

FINAL REPORT

Smart Microgrid Energy Management Controls for Improved
Energy Efficiency and Renewables Integration at DoD
Installations

ESTCP Project EW-200937

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Acronyms

AIRR: Annualized Internal Rate of Return
BACnet: Building Automation Control network. An open communication protocol used for building automation.
BGS: Building gen sets. “Emergency” generators connected to individual buildings.
C90: A Multilin product. In this project, it is coded to manage building loads.
CB: Circuit breaker
CCS: Central Control System. The legacy co-gen controller at Twentynine Palms MCAGCC
CIMPLICITY: GE Intelligent Platforms Supervisory Control and Data Acquisition (SCADA) platform
Co-Gen: Co-generation plant: The combined heat and power plant at Twentynine Palms MCAGCC
DER: Distributed Energy Resources: Power generation sources located within a power distribution system.
DoD: Department of Defense
DPW : Department of Public Works
EMCS : Energy Management Control System. The legacy building and chiller management system at Twentynine Palms MCAGCC.
EnerVista Integrator: A Multilin OPC server for Multilin hardware.
ESTCP: Environmental Security Technology Certification Program. The funding agency for this project.
ESX/ESXi: vmWare’s hypervisor. The virtual machines used to implement the MCS run on ESXi.
FCC: Federal Communication Commission
FSGateway: A protocol conversion tool used in conjunction with RSLinx to communicate with the Rockwell PLC interface for the CCS.
GHG: Greenhouse Gasses:
GHz: Giga Herz
HTHW: High Temperature Hot Water The loop hot water loop supplying Twentynine Palms MCAGCC
ICD: Interface Control Document. The tag description for variables passed between devices.
IEEE: Institute of Electrical and Electronics Engineers
IED: Intelligent Electronic Device
JCI: Johnson Controls, Inc.
LAN : Local Area Network
MCAGCC: Marine Corps Air Ground Combat Center
MCS: Microgrid Control System
Multilin: Manufacturer of the UR90, C90 and EnerVista Integrator
MW: MegaWatt
NAE: Network Automation Engine. JCI’s term for Building controllers located within a building.
NAVFAC: Naval Facilities Engineering Command
NG: Natural Gas
OPC: An open standard that facilitates communication between systems using otherwise incompatible communication protocols.
P: Real power
Pf: Power factor
PLC: Programmable Logic Controller
PV : Photovoltaic
Q: Reactive power
RC4-128: 128 bit Rivest Cipher 4. A common encryption algorithm.
ROM: Rough Order of Magnitude. A term used to indicate that an estimate is based on rough assumptions and is not presumed to be highly accurate.
RSLinx: The Rockwell OPCserver.
SCE: Southern Cal Edison The bulk grid supplier for Twentynine Palms MCAGCC
SIR: Savings to Investment Ratio
SOP : Standard operating Procedure
UR90: Universal Relay 90. The Multilin product upon which the Microgrid optimizer runs.
VM: virtual machine. Used to run multiple “virtual” computers on a single piece of hardware .
Wi-MAX: Worldwide Interoperability for Microwave Access, trademark for a family of communication protocols.

EXECUTIVE SUMMARY

As the title suggests, the project was aimed at developing microgrid energy management controls for improved energy efficiency and renewable integration at DOD installations. The microgrid control system (MCS) demonstrated in this project is designed to manage and control the complicated interactions among heat and electrical power generation, power demand, energy storage, and power distribution and delivery. The advanced control and optimization functions include optimal dispatch of distributed energy resources or DERs (including renewable and energy storage), initial capability of load management during grid connected or islanded operation, and energy efficiency optimization by simultaneously controlling DERs for maximum efficiency and managing the major electrical loads. The important technology contributions to improving energy efficiency and increasing energy security are (1) the ability to include various assets such as renewables, combined heat and power units, electrical and thermal storage, and controllable loads as energy management resources; (2) the ability to include future predicted values of loads, renewable generation, and fuel and electricity prices in the optimization process; (3) the ability to automatically commit / de-commit DERs as needed; and (4) the use of a predictive control strategy to address renewable generation intermittency. The optimal dispatch problem is suitably formulated so that it can be solved using computationally efficient and robust optimization algorithms.

The current state-of-the-art power grid includes minimal renewable or clean energy, no intelligent distribution, minimal or no energy storage, ad hoc dispatch, uncontrolled load demands, and excessive distribution losses. Microgrids are envisioned as local power networks that utilize distributed energy resources (DER) and manage the local energy supply and demand. While microgrids would typically operate connected to the national bulk power transmission and distribution system, they would have the ability to disconnect from the grid and function in 'island mode' when necessary.

Implementation of this technology is expected to lead to improved energy efficiency and reduced fossil fuel use, increased energy security and power system reliability that enables continuous military base operation, and reduced carbon footprint and greenhouse gas emissions. The technology is scalable (i.e., it can handle small [several hundred kilowatt] to large [several tens of megawatts] microgrids) and is transferrable to multiple DoD installations that contain various types of renewable resources.

The objective of this project is to demonstrate advanced microgrid control technologies capable of improving energy efficiency, expanding use of renewables, and increasing energy security for the Department of Defense (DoD). The MCS technologies developed for this project is analyzed via a field demonstration at the selected DoD installation site as well as multiple laboratory tests with the field data, to validate the technology's performance and expected operational costs. The ability of the technology to improve the energy efficiency, enable renewable integration, increase energy security, and reduce operational cost is evaluated by comparing system performance to a baseline of the Twentynine Palms site operation. The goal is to enable this promising technology to receive regulatory and end user acceptance and be fielded and commercialized more rapidly.

Table 1 shows the performance objectives and the outcomes from demonstration and testing.

Table 1: Performance Objectives and Outcomes

Performance Objective	Metric	Data Requirements	Success Criteria	Results
Quantitative Performance Objectives				
Increased renewable energy usage and reduced fossil fuel usage	Ability to optimize more renewables and natural gas based resource	Estimate potential displacement of fossil fuel based generation by using renewables and other natural gas based DGs. Calculate GHG emissions reduced.	Capability to use and optimize up to 100% of emission-free energy resources.	As described by the results in section 5.2, 100% of the renewables were used all the time.
Increased energy efficiency	Operate DGs and boilers at their highest power factor and efficiency regions	Power time histories – imported power, generated electrical power by the DGs, generated thermal power; NG and boiler usage	Comparing with using multiple DGs and boilers used to meet the same demand, microgrid controller can show up to 2-3% efficiency over the year improvements in a microgrid with a few boilers and one CHP. This number is expected to increase to 10-15% with more CHPs and energy storage.	As discussed in the results of section 5.2, adjusting the heat vs. electrical outputs of the CHP 2-4% efficiency is possible in a conservative estimate. In certain situations and definitely with more assets much bigger increase is possible.
Increased energy surety	% of extra critical loads that can be served in absence of grid power	% of non-critical load reduction (e.g. 2 degree increase in thermostat settings) in building loads	Based on the availability of non-critical loads during the hours of islanding, the target is to serve 10% of extra critical loads and hence provide nearly 100% longer service to this 10% load assuming that Cogen capability remaining same all through the islanded operation.	As discussed in the results of section 5.2, a sizable amount of electric load can be dropped instantly by managing the building loads. Depending on the number of buildings participating, 10% of reduction of aggregated loads is possible in few seconds to 10-15 minutes timescale without tripping the whole building or sacrificing too much comfort.

Table 1: Performance Objectives and Outcomes (Contd.)

Performance Objective	Metric	Data Requirements	Success Criteria	Results
Qualitative Performance Objectives				
Regulatory and End User Acceptance	Degree of Acceptance	During training and demonstration show how microgrid can be a “win-win” proposition between regulators and end-users	Favorable response from the microgrid operators as well as their interactions with the utility/regulators.	As described in section 5.2, favorable response is obtained from the microgrid operators. Also the project received good feedback during presentations at the conferences with utility representatives.
User satisfaction	Degree of favorability	Informal Interviews	Favorable opinions and constructive comments expressed by stakeholders.	Informal discussions with the Base personnel were very favorable. The key testimony was their desire to expand the technology for rest of the Base.

Based on these outputs and following NIST guidelines, SIR (Savings to Investment Ratios) and AIRR (Annualized Internal Rate of Return) are calculated for six alternative scenarios. They are:

- 1) Baseline: this is based on available yearly energy consumption data from the Base
- 2) Optimal Dispatch Technology with minimal assets – this assumes about 2-3% energy efficiency benefits as described in section 5.2.
- 3) Optimal Dispatch with all assets – this assumes all the planned assets in the Base are deployed (additional CHPs, fuel cell, energy storage etc.)
- 4) Load Management – benefits of energy efficiency on load management is considered.
- 5) Optimal Dispatch and Load Management combined
- 6) Optimal Dispatch with Renewables: as described in section 5.2, this alternative is considered only to determine the benefits obtained by GHG emission reduction.

Table 2 summarizes these cost-benefit results.

Table 2: Cost Benefit Summary

Case	SIR	AIRR	Total savings	% energy used	Emission (Tonnes/year)		
					CO2	SO2	NOx
Baseline, 29Palms (estimated)	NA	NA	\$0	100%	71948	479	95
Optimal Dispatch with Minimal Assets	6.59	13%	\$4,218,818	98%	51733	314	51
Optimal Dispatch With All Assets	11.54	16%	\$7,386,162	98% for 3 years, 95% for next 9 years and 90% thereafter	51176	314	51
Load Management Only	2.05	7%	\$3,682,421	99% for 4 years, 98% for next 5 years, 96% for next 5 years and 95% thereafter	51596	314	51
Optimal Dispatch with Load Management	4.19	11%	\$8,465,257	97% for 3 years, 93% for next 6 years, 91% for next 3 years, 85% thereafter	50783	314	50
Optimal Dispatch with Renewables	Not calculated, varies for different types of renewable resources and their costs				50538	314	50
Difference in emission (baseline with renewables)					21410	165	45

The project had a relatively seamless implementation and system integration during the demonstration phase due to excellent camaraderie and support provided by the Base engineers and members of their Energy Service Provider (Johnson Controls Inc.). Without their cooperation and teamwork, this project would not have reached this stage of success. There are a few lessons learnt that are discussed in this report, which can aid future implementation of the technology. Some of them are inability to export excess power generated by its DERs to the outer grid, lack of variable pricing schemes, inability to do continuous set-point control of diesel gensets due to EPA regulations, unavailability of state-of-the-art solar inverters, non-operational assets like the fuel cell etc.

The method by which the technology will be transitioned to the DoD end user(s) involves the actual usage of the MCS on the base's identified microgrid via GE Digital Energy (microgrid controller and volt/VAr control) and GE Intelligent Platforms (supervisory controller, the HMI, the BEM, and certified network communications) hardware and software tailored for the Twentynine Palms operation. GE can specify the technology transfer method for the appropriate audience. The GE proposed hardware and software initially developed for Twentynine Palms can be utilized for additional DoD bases with limited modifications. GE has some relationships with other DoD bases and will work with DoD ESTCP to identify other DoD bases for follow-on installations.

1.0 INTRODUCTION

The current state-of-the-art power grid includes minimal renewable or clean energy, no intelligent distribution, minimal or no energy storage, ad hoc dispatch, uncontrolled load demands, and excessive distribution losses. Microgrids are envisioned as local power networks that utilize distributed energy resources (DER) and manage the local energy supply and demand. While microgrids would typically operate connected to the national bulk power transmission and distribution system, they would have the ability to disconnect from the grid and function in 'island mode' when necessary.

1.1 BACKGROUND

The microgrid control system (MCS) to be demonstrated is designed to manage and control the complicated interactions among heat and electrical power generation, power demand, energy storage, and power distribution and delivery. The MCS also can optimize energy usage and offers energy security by maintaining PV and managing backup power operation for critical loads in the event the microgrid is disconnected from the bulk grid (or islanded). The advanced control and optimization functions include optimal dispatch of distributed energy resources or DERs (including renewable and energy storage), initial capability of load management during grid connected or islanded operation, and energy efficiency optimization by simultaneously controlling DERs for maximum efficiency and managing the major electrical loads. The important technology contributions to improving energy efficiency and increasing energy security are (1) the ability to include various assets such as renewables, combined heat and power units, electrical and thermal storage, and controllable loads as energy management resources; (2) the ability to include future predicted values of loads, renewable generation, and fuel and electricity prices in the optimization process; (3) the ability to automatically commit / de-commit DERs as needed; and (4) the use of a predictive control strategy to address renewable generation intermittency. The optimal dispatch problem is suitably formulated so that it can be solved using computationally efficient and robust optimization algorithms.

Implementation of this technology is expected to lead to improved energy efficiency and reduced fossil fuel use, increased energy security and power system reliability that enables continuous military base operation, and reduced carbon footprint and carbon dioxide emissions. The technology is scalable (i.e., it can handle small [several hundred kilowatt] to large [several tens of megawatts] microgrids) and is transferrable to multiple DoD installations that contain various types of renewable resources.

1.2 OBJECTIVE OF THE DEMONSTRATION

The objective of this project is to demonstrate advanced microgrid control technologies capable of improving energy efficiency, expanding use of renewables, and increasing energy security for the Department of Defense (DoD). The MCS technologies developed for this project is analyzed via a field demonstration at the selected DoD installation site as well as multiple laboratory tests with the field data, to validate the technology's performance and expected operational costs. The ability of the technology to improve the energy efficiency/life cycle, increase energy security, and reduce cost is evaluated by comparing system performance to a baseline of the Twentynine Palms site operation. The goal is to enable this promising technology to receive regulatory and end user acceptance and be fielded and commercialized more rapidly.

1.3 REGULATORY DRIVERS

The existing regulations, Executive Orders, DoD directives have resulted in a need for a new microgrid control technology includes:

1. Energy Policy Act of 2005,
2. Executive Order 13423,
3. Energy Independence and Security Act of 2007,
4. Secretary of the Navy mandates,
5. State mandates, and
6. IEEE 1547-2003: IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems

2.0 TECHNOLOGY DESCRIPTION

2.1 TECHNOLOGY OVERVIEW

Microgrids are local power systems that use DER to manage the local energy supply and demand. They increase the viability of DER in the bulk grid by aggregating them into clusters with better grid stability properties than a multiplicity of standalone generators. They have the ability to separate themselves from the bulk grid and function in island mode, so they have the potential to enhance grid resiliency and customer reliability and security by reducing susceptibility to faults and disturbances. At a high level, the interest in microgrid power systems is driven by a growing desire to locate DER closer to load centers. This interest in DER is being fuelled by a number of factors, including:

- Transmission congestion, and problems with siting new transmission lines, make it appealing to site DER in distribution systems to cope with new loads
- Utilization of DER can help utilities defer investments in generation and transmission capacity
- DER have the potential to offer increased total energy efficiency when used with combined heat and power (CHP) or combined cooling heat and power, and can therefore reduce energy costs
- Appropriately integrated DER can improve power availability and quality
- Distributed systems offer potential security advantages over centralized systems
- DER promote fuel diversity (e.g., biomass, landfill gas, flare gas, wind, solar) and therefore reduce overall energy price volatility
- Renewable DER such as wind and solar photovoltaics provide emissions-free energy
- DER offer a quicker solution with regards to installation, lead time and siting relative to centralized generation

While all of these benefits make DER attractive, the primary concern at the utility level is the system operation and protection issues associated with the existence of a large number of independent power producing assets operating without coordination. Microgrids offer a framework that resolves this concern through the aggregation of DER into well-behaved entities that can be dispatched by the utilities, as shown in Figure 1. The capability for microgrids to disconnect from the bulk grid to operate in an island mode will provide the end-users with better availability than DER alone. DERs within the microgrid are equipped with local controllers that regulate real power, reactive power, frequency, and/or voltage. Intelligent electric devices (IEDs) located elsewhere in the microgrid provide system loading, voltage, and frequency information and carry out switching operations. The Microgrid Control System (MCS) implements a centralized, supervisory control layer. It polls all resources, executes central control algorithms, and sends resulting control commands back to each resource. The MCS is built on a utility-grade, embedded processor platform. A microgrid LAN provides the communications infrastructure. Ethernet is easily extendable and supports multiple protocols, accommodating a broad range of devices and services. The hardware supports fiber-optic cabling which is immune to ground potential differences and transients generated by faults or switching events. Remote resources are integrated into the LAN using wireless Ethernet devices. These devices incorporate frequency hopping and spread spectrum radio for high reliability. Data is encrypted using RC4-

128 with automatic key rotation. Distances of up to 10 km are supported. Key features of this architecture include:

- Support of centralized and distributed approaches
- Adaptability of a broad range of energy technologies
- Flexibility to accommodate current and future applications

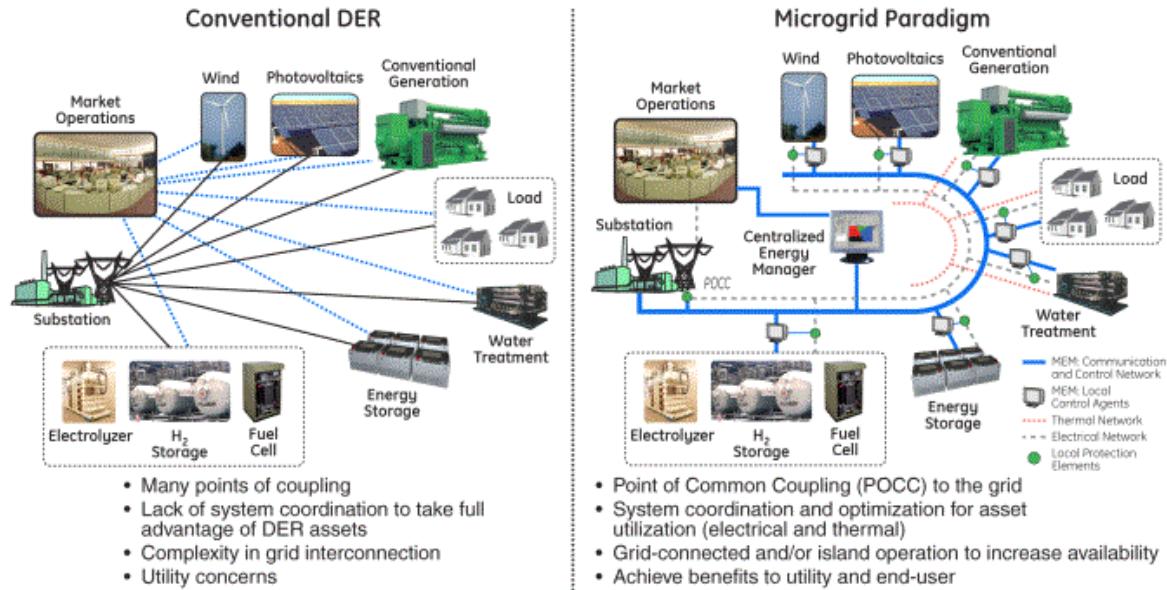


Figure 1: Microgrid Paradigm

2.2 MODEL PREDICTIVE CONTROL

Model predictive control (MPC, Figure 2) is used for optimal dispatch in the microgrid. In this method, a model of the process to be controlled is used to evaluate the behavior of process outputs in response to control inputs. The model response is evaluated for a finite period extending into the future, known as a prediction horizon. The outputs are optimized over this period in order to arrive at the ideal values of outputs to be applied at the current time.

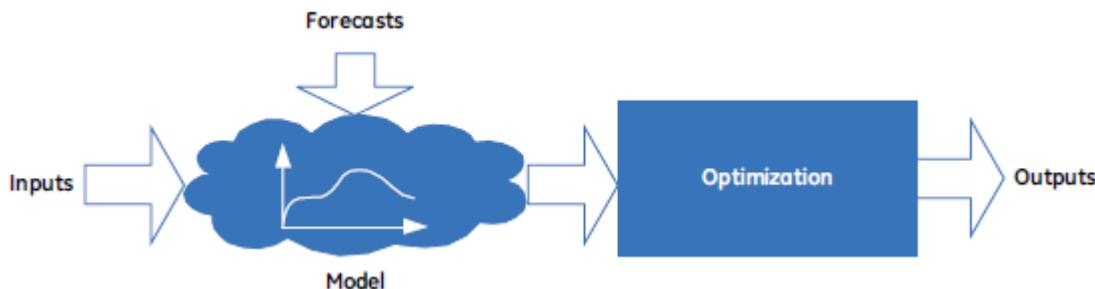


Figure 2: Model predictive control

Applied to the dispatch challenge, inputs represent internal physical states of the process such as offline/online, availability, isochronous operation, storage state of charge, and metered power of the devices. Generators and storage devices are modeled by their power ratings and efficiency curves. Forecasts model the loading of the power system, the contribution of renewable sources, and the price of grid power (if one exists). Finally, outputs take the form of start/stop commands and power reference commands applied to generators and storage devices.

Generation must match load in a stable power system. Dispatchable generation including the storage equals the total load minus the total power supplied by renewable sources. These resources are assumed to have local controllers that are designed to maximize the use of available renewable energy.

The problem to be solved by the U90Plus is a multi-interval optimization problem. As shown in the following figure, an assumed prediction horizon of 24 hours is divided into multiple time steps/intervals, such as 120 twelve-minute or 240 six-minute time intervals (Figure 3).

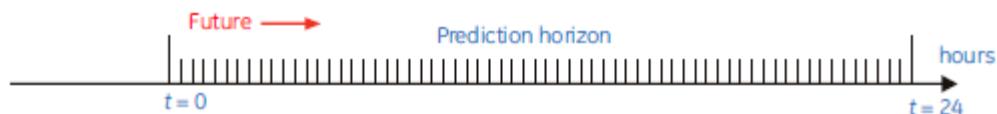


Figure 3: Prediction horizon

Different routines within the optimization framework are formulated and solved at each time step (for example, 12 minutes) over the prediction horizon (24 hours) based on load, renewable resources, and price forecasts. In this framework, a variety of operational considerations are factored in. These include and are not limited to the support of a hydro unit in isochronous mode, minimum up/down times required for storage charging, interaction with the grid, and support of manual-start dispatchable generators.

The objective function of the optimization problem can, in general, include the following terms:

- Fuel/operation costs of all power generation devices in the microgrid
- Cost/incentive terms for storage device charging/discharging. These are more subjectively determined, being driven by the requirement to prevent simultaneous charging and discharging and the need to limit storage cycling.
- Penalty terms mainly related to those generation/storage devices allowed to have their limits on minimum powers violated (that is, having soft constraints)
- Power importing/exporting costs/revenues when the microgrid is grid-connected

Also, the constraints of the optimization problem capture the following limitations for both electrical and thermal systems:

- Minimum and maximum values of generated power with the consideration of their isochronous or non-isochronous operation, and the microgrid reserve margin requirements
- Limits on importing/exporting powers considering the microgrid reserve power requirements (for grid-connected microgrids)

- Power balance in the microgrid considering the contribution of power generation/storage devices, load, and any grid
- Minimum, maximum, and initial values of storage devices state of charge
- Limits on storage input and output powers
- The energy balance equation of storage devices representing the storage state of charge in each time step based on its value in the previous time step as well as charging and discharging powers with the consideration of the related efficiencies and standby losses

When the prediction horizon is long enough, the algorithm can determine when to charge storage, because it can anticipate times when the loads are large and when the stored power can be utilized. The optimal dispatch algorithm implemented within the microgrid controller can be configured for up to 32 resources. Assuming a worst-case scenario where all resources are committed, the optimization problem can have on the order of 20,000 variables and 40,000 constraints.

2.3 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

It is anticipated that the project will deliver: 1) an advanced MCS with enhanced and added features and functions including optimal dispatch of DER, and load/energy management; and 2) a field demonstration system at a suitable DoD installation and Twentynine Palms Marine Corps is the site for the demonstration. The expected benefits of the project are improved energy efficiency and reduced fossil fuel cost, increased energy security and power system reliability enabling military base continuous operation, and reduced carbon footprint and CO₂ emissions. The technology is scalable to multiple DoD installations.

The benefits of the technology are tied to amount of DER available in a given microgrid. For grid-connected microgrids with limited number of DERs, the benefits of optimal dispatch will be relatively small. Also if this microgrid is connected to a stable utility grid which provides high reliability, then the microgrid will not need too many islanding operations. On the other side, another limitation to demonstrate benefits can be seen if the available DERs are of much higher capacity than the available controllable loads. In this case load management is not needed during islanding as the DERs can easily support all of these loads.

3.0 SITE/FACILITY DESCRIPTION

The MCS is demonstrated at Twentynine Palms Marine Base in California, the largest marine base in the country.

3.1 SITE/FACILITY LOCATION, OPERATIONS AND CONDITIONS

Among the candidate sites considered, Twentynine Palms Marine Corps located in California ranked the highest and is therefore selected as the site for the demonstration. Twentynine Palms has 7 acres of solar PV that total more than 1 MW, as well as a gas-fired cogeneration plant in excess of 7 MW. In the future, additional solar PV, fuel cells and advanced energy storage systems may also be added to the marine base's on-site resource mix. The single line diagram of the Twentynine Palms power distribution system and a picture of the base are shown in Figure 4. It is connected with the Southern California Edison utility grid at the Ocotillo substation. Some parts of the Cogen Facility under Substation AA is used for demonstrating the microgrid.

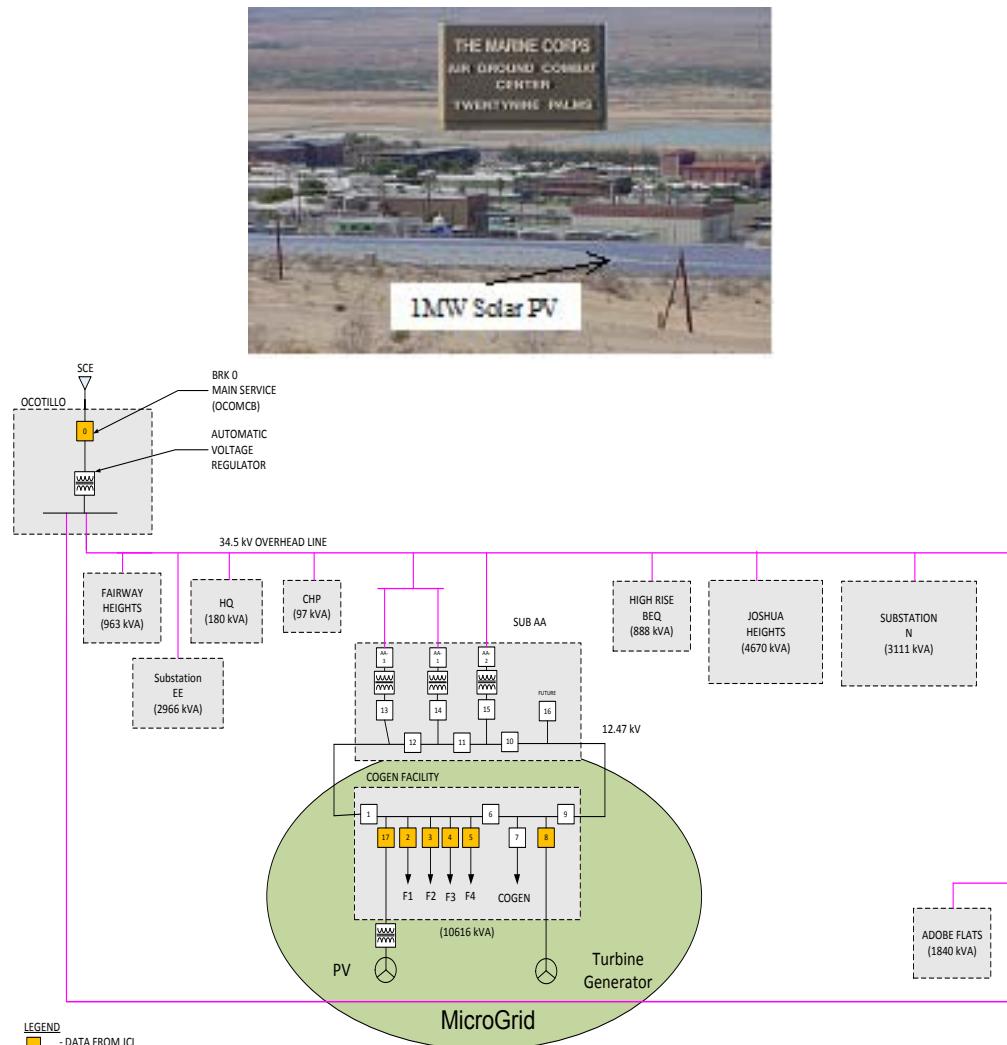


Figure 4: Twentynine Palms Marine Corps site and the Electrical Single Line Diagram

This site has an installed 7.2 MW gas turbine co-gen facility that supports base electric and high temperature hot water loads. It has diesel Gensets and will have fuel cell systems on-site as well. It also currently has a 1MW solar PV system with plans to add additional MWs in coming years. The substations that power the base are being upgraded with automation equipment, smart meters, and sensor devices. The Twentynine Palms base was chosen because of the variety of DG resources available as well as planned in the near future and also because of its planned active participation in the deployment of smart grid technology. This is an ideal site to demonstrate the MCS technologies developed at GE.

Following is the list of distributed generation assets available at the Base:

- 1) One combined heat and power unit (CHP) of 7.2MW capacity. Two more CHPs are being commissioned and will be ready by beginning of 2013.
- 2) One PV plant of 1MW rating. There are distributed PV modules all through the base (rooftops, parking lots etc.) which are currently not used in the energy management but are estimated to be about 2-3 MW total capacity.
- 3) Diesel gensets in about 35-40 buildings with a total capacity of around 4MW. However these units can be used only for emergency purpose and can't be used for regular microgrid operations due to environmental constraints from EPA.
- 4) A fuel cell unit, currently non-functional.
- 5) In 2013, based on another ESTCP funded project, an energy storage system of 1MW, 576kWh rating will be installed.
- 6) There are three main boilers available to provide the bulk of heating loads at the Base.

3.2 SITE/FACILITY IMPLEMENTATION CRITERIA

The objective of the demonstration at a DoD installation site is to further validate, refine, and transition the microgrid control and building energy management technologies to commercialization. It allows the developers to collect real-time data and feedback, and identify gaps and shortfalls for further improvement and next generation design. It also gives users first-hand experience in using and interfacing with the new technology and product. GE had worked with the DoD assigned liaison in selecting the site for demonstration. A subset of the criteria used for site selection includes:

- Government furnished equipment
- DG resources (solar PV, diesel Genset, fuel cell and combined heat and power/CHP) available now and plans for future additions
- Availability or plan for energy storage
- Consumer acceptance and participation in smart grid technology
- Controllable building loads such as HVAC and chiller
- Electricity cost and plans to incorporate variable electricity pricing
- Advanced metering infrastructure and Ethernet communication infrastructure
- Capability or flexibility of upgrading legacy generator control systems
- Geographical location and climate of the site

- Necessary funding available to implement the balance of the project

All the existing and planned resources were evaluated and taken into consideration in the site selection process. A number of candidate sites were identified then evaluated against the criteria. A Pugh analysis was used to rank the sites quantitatively. Each criterion was first assigned a weight based on its importance to the technology and the demonstration. Each site was then compared against a chosen baseline/reference site. A weighted score was then calculated. The highest scores are the leading candidate sites.

3.4 SITE-RELATED PERMITS AND REGULATIONS

Discussions with site personnel have been, and continue to be, held. As per those conversations, the current status regarding permits and regulations are:

- FCC permits for 3.65 GHz WiMAX radios: The site is responsible for acquiring these.
- Other hardware installations: The site is responsible for acquiring these.
- Software installations: Discussions are ongoing with the power system contractor, JCI, regarding specific requirements. Mutually agreeable requirements were identified and met prior to the demonstration.
- Necessary third party notifications: According to site personnel, none are needed.
- Environmental constraints: The site environmental controls office has been consulted. GE has received verbal approval; site personnel may have written documentation.
- Health and Safety: Site documents have been received and are under review by GE. Compliance with both site and GE standards are maintained.
- Existing Interconnection requirements: There is no interconnection requirement that directly affects the testing and demonstration of the microgrid controller. However the microgrid controller can provide better solution if the Base can export power to the utility grid during periods of low load and higher available generation – a service which is not in place yet. Twentynine Palms energy manager is working with the utility to negotiate this aspect. Also there is a minimum import requirement which needs to be met all through the year; else a penalty will be incurred.

4.0 TEST DESIGN AND ISSUE RESOLUTION

The fundamental problem addressed by this project and which this demonstration is intended to show improvement, is improved energy surety. Heavy reliance upon imported power degrades energy surety, thus this project develops and field tests techniques to reduce reliance upon import power. Energy surety also improves as local power generation assets can be fully utilized. At Twentynine Palms MCAGCC, there is room for improvement in both areas. This demonstration will assess the degree to which the MCS can effectively improve local generation efficiency and local power source integration. In addition, the demonstration will provide data necessary for to assess how well the MCS can handle energy surety aspects both during grid-tied as well as islanded operation. Impact on the operator work load will also be assessed.

4.1 CONCEPTUAL TEST DESIGN

The performance objectives are listed in Table 1. This section specifies conceptual background for testing each item described in Section 4.

- *Increased renewable energy usage and reduced fossil fuel usage:* this influences the conceptual design of the objective function of optimization to a large extent. So during testing, it needs to be ensured that renewable energy resources are getting a higher priority and kept “available” most of the time. The testing needs to be designed in a way so that not both the amount of renewable energy used as well as the availability factor are tracked for renewable under any grid conditions.
- *Increased energy efficiency:* to ensure this highest possible efficiency from the equipment is inputted in the settings file. During operation, both electrical and thermal energy needed to operate the DGs and boilers are tracked – so these appropriate parameters need to be tracked from the HMI.
- *Increased energy surety:* the HMI needs to be designed such a way that the total building load is tracked. This will enable to track how much reduction of non-critical loads is possible when for example, a thermostat setting is changed. For this necessary communication between the building controls and the MCS are established. This factor is taken into account in the communication design.
- *User Satisfaction and Acceptance:* Reducing operator involvement with low-level control operations will allow the operator to monitor overall system status and identify anomalous events. Data will need to be collected on the operations the operator would take for different events. User satisfaction needs to be guaranteed by co-locating the user interfaces through bigger visual inputs and designing seamless operation from one screen to another.

4.2 BASELINE CHARACTERIZATION

Baselines are required for all of the data mentioned in Section 5.1.

- Reference Conditions: The data that will be collected include:
 - PV power output, power factor and voltage.
 - Co-gen power output, power factor and voltage.
 - SCE power imported through Ocotillo, power factor and voltage.
 - Loads per feeder in the Co-gen switchyard (including load per phase).
 - Loads at each temporary building (including load per phase).

- Performance data for each controllable microgrid asset (response times, states before and after the control event)
- Operator performance data for operator-initiated events (response times, states before and after the control event).
- Baseline Collection Period: Some of the required data is collected regularly at the base. To the extent possible, this data will be used. Data that is not normally archived are collected over a three month period.
- Existing Baseline Data:
 - PV power output, power factor and voltage.
 - Co-gen power output, power factor and voltage.
 - SCE power imported through Ocotillo, power factor and voltage.
 - Loads per feeder in the Co-gen switchyard. Per-phase load data is not available.
 - Transition to islanding standard operating procedure.
- Baseline Estimation: Baseline estimation will only be used to replace bad or missing data. In all cases, estimations are based on other historical data. The algorithms used were developed at GE-Global Research using system data previously provided by Twentynine Palms.
- Data Collection Equipment: All data will originate either in the controllable asset, or in the associated relay. No specialized sensors are needed.

4.3 DESIGN AND LAYOUT OF SYSTEM COMPONENTS

Figure 5 shows the key microgrid control system components. Controllable assets key to microgrid management include:

- The combine heat and power unit (CHP).
- Boilers (either manual or automated control, as available)
- Buildings: These can be controlled by Cimlicity and/or smart load panels.
- Legacy assets: The MCS will control those via the existing control systems.
 - Central Control system (CCS): A Rockwell (Allen-Bradley) controller.
 - EMCS: Johnson Controls Network automation Engine (NAE).

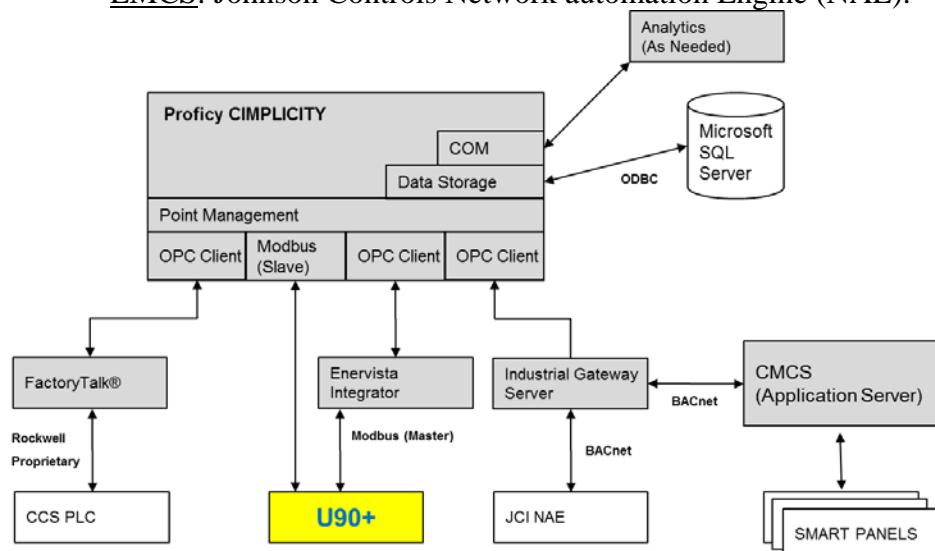


Figure 5: Block diagram of Microgrid control system components

- System Components: This demonstration is intended to collect data sufficient to model all the MCS's capabilities. The central physical components are:
 - the communication hub, operating in a Dell server
 - the Optimal dispatch engine, operating in a Multilin UR90+
 - initial building load management set up, can be done either from the GE Cimilarity layer or by operating a GE device called C90. At this point, the former approach is taken.
- System Integration: The MCS will leverage the existing EMCS and CCS control systems. With the exception of adding the capability to communicate with the MCS and execute MCS commands, the existing EMCS and CCS will not be changed. The MCS failure path shifts microgrid control to the existing systems. In addition, the MCS includes an advisory state, where recommended MCS actions are displayed on the HMI, but operators remain in control.
- Virtual Machines: The MCS consists of four Virtual Machines (VM). The VMware hypervisor (ESXi host) has the capacity to run three MCS virtual machines as well as the VMware host management add-on, vMA. The virtual environment provides six virtual switches, each tied to a physical port. In order to isolate potential faults, each subsystem communicates on a dedicated network. Virtualization also enables resource sharing, thus satisfies the need to minimize resource consumption on-site. In a virtual environment, each virtual machine is a module and the virtual network(s) connecting them enable interface creation. Thus OS layer modularization can be effected using virtualization; a key capability is rapid configuration. In addition, a virtual environment can be stored as a configuration file and snapshots made of virtual machines. Recovery from a failure down to the OS level or replacing a corrupt virtual environment can be done fairly easily from the configuration file.
- System Controls: Visibility into, and operator interaction with, the MCS are provided through the existing operator's console. Figure 6, Figure 7 and Figure 8 show screenshots of some of the system information provided on controllable assets.
- Data Collection: Baseline and new performance data are collected from April till November 2012 for the current phase report. However GE and the Base are very interested to continue collecting data beyond the current phase and the performance results will be provided to DoD periodically.

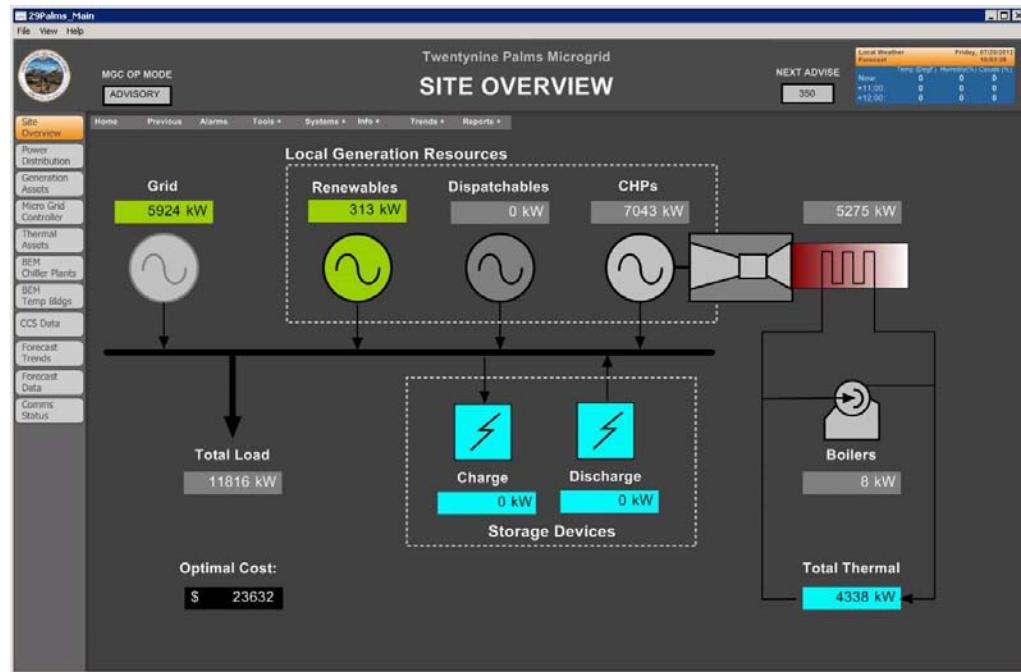


Figure 6: MCS site overview screen



Figure 7: MCS DER electrical assets managed

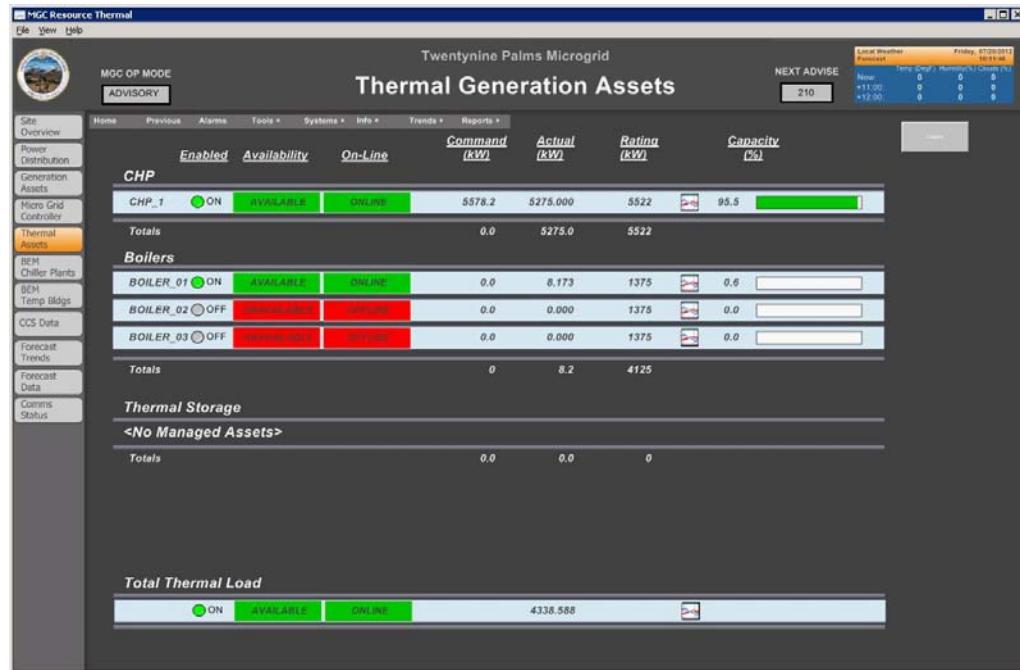


Figure 8: MCS DER thermal assets managed

4.4 OPERATIONAL TESTING

Provide a description of each significant operational phase of the technology the investigator will assess.

- Operational Testing: Testing consisted of the following phases:
- MCS Advisory Mode tests conducted are:
 - Set all MCS controllable assets to Advisory mode.
 - Confirmed that the MCS data logger and UR data loggers are active.
 - Confirmed that all inputs into the MGC are correct.
 - Continuously monitoring the system.
 - Making regular backups of the data.
- MCS Auto Mode tests conducted are:
 - Made a final backup off Advisory mode test data.
 - Cleared data logs.
 - Set all MCS controllable assets to Auto mode in U90+ without making final connection with the end equipment with Cimlicity.
 - Monitored system operation over long period.
 - Verified that The MCS is correctly optimizing microgrid operation.
 - Made regular backups of the data.
 - The final connection of its commands to the actual equipment is being planned after the Base engineers fully learn operation of the controller and the fallback features.
- Load Management Test Procedure
 - Confirmed that the MCS is operating in full-auto, grid-tied mode.
 - Sent signal to CIMALICITY (as if islanding is taking place)

- Tested the MGC changing the mode for isochronous operation.
 - Tested that load management section in Cimplicity sent out commands to the loads (building thermostats)
 - Load controllers execute the command
 - Measured the specific load profiles before, during and after the event.
 - Reconnected the loads back on after 60 minutes and continued collecting data for some more time to make sure all thermal loads are properly accounted for during this event.
- Modeling and Simulation: Data collected during active testing were used to model the Twentynine Palms microgrid in the GE-GR Smart Grid lab, to the level it is deemed appropriate for testing and validation. This is extensively described in Appendix A.
- Timeline: Installation and commissioning was done by a visit to the Base in a week. Subsequent visits were made to perform more testing, tuning and software upgrades.
- Decommissioning or Technology Transfer: At the close of testing, the DoD will be given the option to retain the equipment and control system. If that option is exercised, then GE will provide materials such as manuals, schematics, etc. suitable for day-to-day operations. GE-GR is not a production facility, so does not provide long-term operational support. However, all equipment provided is commercially available hardware, so post-project support will be available through the vendors.

4.6 SAMPLING PROTOCOL

The sampling protocol should result in the collection of relevant and sufficient data to validate the technology cost and performance under real-world conditions.

- Data Description: Data will consist of time-stamped microgrid system state data and associated event and command-response logs. Specific data are listed in the ICD.
- Data Collector(s): Data collection shall be built in to the MCS, so shall be automated. Human involvement should be limited to test set up (as required) and error management.
- Data Recording: The automated data collection will occur over a three-month period; sampling frequency will depend on the type of operation.
- Data Storage and Backup: Initial data storage shall be on the ESX box. The ESX datastore is configured as a RAID. Depending upon existing base equipment capacity, a daily data backup shall either be stored on the Operator's computer or on an external hard drive. Total data collected is not expected to exceed 10GB.
- Data Collection Diagram: Data originate at remote Microgrid devices. Their locations span the Microgrid. All data, however, flows to the MCS.
- Survey Questionnaires: There will be no formal surveys. At the close of testing, site personnel actively involved in MCS operation will be asked for comments and suggestions.

4.7 EQUIPMENT CALIBRATION AND DATA QUALITY ISSUES

- Equipment Calibration: All the equipment installed at the site will be calibrated by trained GE engineers and site engineers.
- Quality Assurance Sampling: The data sampling frequency is sufficiently high to characterize random errors. Data acquisition dropouts are marked to avoid contaminating

valid data. In some cases, e.g. load and generation measurements, totals can be compared for consistency.

- Post-Processing Statistical Analysis: In order to assess result quality, standard statistical analysis shall be applied. For example, where applicable, confidence intervals shall be measured.

4.8 SAMPLING RESULTS

A snapshot of 5-minute interval data collected is shown in Table 3. The actual data is collected in SQL database by the Base engineers. This data is transferred to GE and later extracted in MS Excel format as shown in the Table. The actual data files have 42 parameters which include timestamp, power measurement of different assets (in kW), temperatures, online/offline, breaker status etc. Only some of them are shown in the Table for illustration purpose only. Some of these important parameters are then plotted and shown in Figure 9. This gives valuable information on specific days where there were specific events (e.g. grid outage or CHP offline etc.) and need further analysis.

Table 3: Sampling Results

timestamp		timestamp_utc		MGC_B01A_VALIDITY_VAL	MGC_B01ONLINE_VAL	MGC_B01PW_R_METER_KW_VAL	MGC_B01RM_GC_OP_MODE_VAL	MGC_B01ONLINE_VAL	MGC_B01PW_R_METER_KW_VAL	MGC_B01A_VALIDITY_VAL	MGC_B01IOP_MODE_VAL	MGC_B01IOULINE_VAL	MGC_B01DP_WR_METER_VAL	MGC_B01AVAILABLE_VAL	MGC_B01GRDMODEL_VAL	MGC_B01GRD_AVNUAL_VAL	MGC_B01GRDPWR_METER_VAL	MGC_B01CHPNELECT_METER_VAL	MGC_B01CHP1_METER_VAL	MGC_B01HLP_METER_VAL
4/19/2022	5:45:13 PM	4/19/2019	9:45:33 PM	1	1	7638.016895	0	1	697.2147217	1	1	14720.5264	1	0	1	6958.33008	7049.80057	25.4748383	7048.81689	7048.81689
4/19/2022	5:40:13 PM	4/19/2019	9:40:33 PM	1	1	7927.428288	0	1	695.8253784	1	0	14480.4463	1	0	1	6747.74219	7069.1293	26.3984921	7027.42833	7027.42833
4/19/2022	5:35:13 PM	4/19/2019	9:35:33 PM	1	1	7648.055125	0	1	677.0427258	1	0	14233.9901	1	0	1	6860.43213	7055.15821	26.4575841	7048.05512	7048.05512
4/19/2022	5:30:13 PM	4/19/2019	9:30:33 PM	1	1	7723.70605	0	1	700.191221	1	0	14206.6074	1	0	1	6881.71774	7054.422148	26.2901899	723.07651	723.07651
4/19/2022	5:25:13 PM	4/19/2019	9:25:33 PM	1	1	8381.284181	0	1	700.574463	1	0	14020.1973	1	0	1	6231.16113	7010.61265	26.3707974	830.37079	830.37079
4/19/2022	5:20:13 PM	4/19/2019	9:20:33 PM	1	1	8450.161133	0	1	696.458129	1	0	13972.5469	1	0	1	6235.0732	7056.76953	26.752599	4560.1613	4560.1613
4/19/2022	5:15:13 PM	4/19/2019	9:15:33 PM	1	1	7863.48291	0	1	694.883397	1	0	14168.7627	1	0	1	6397.05316	7063.2857	25.5309878	7863.48291	7863.48291
4/19/2022	5:10:13 PM	4/19/2019	9:10:33 PM	1	1	8035.87047	0	1	702.9417114	1	0	13905.1475	1	0	1	6116.57373	7063.85027	26.6234586	805.8705	805.8705
4/19/2022	5:05:13 PM	4/19/2019	9:05:33 PM	1	1	8421.76855	0	1	701.405093	1	0	13653.6924	1	0	1	5884.16991	7054.75473	27.4962657	8421.76855	8421.76855
4/19/2022	5:00:13 PM	4/19/2019	9:00:33 PM	1	1	7646.654508	0	1	686.4937012	1	0	13725.2301	1	0	1	5963.34062	7063.58887	26.4963196	7646.65451	7646.65451
4/19/2022	4:55:13 PM	4/19/2019	8:55:33 PM	1	1	7293.150391	0	1	708.856246	1	0	13640.7969	1	0	1	5884.23584	7064.83105	25.3655529	7306.77067	7306.77067
4/19/2022	4:50:13 PM	4/19/2019	8:50:33 PM	1	1	7416.850098	0	1	697.6581421	1	0	13776.9072	1	0	1	6067.62679	7049.70636	25.1407776	7416.85009	7416.85009
4/19/2022	4:45:13 PM	4/19/2019	8:45:33 PM	1	1	8867.564543	0	1	705.2403244	1	0	14164.7129	1	0	1	6384.03223	7010.89941	25.5529938	8676.56454	8676.56454
4/19/2022	4:40:13 PM	4/19/2019	8:40:33 PM	1	1	9251.362305	0	1	714.695922	1	0	13799.6807	1	0	1	6087.61328	7054.04018	26.3049895	9251.36230	9251.36230
4/19/2022	4:35:13 PM	4/19/2019	8:35:33 PM	1	1	9026.401367	0	1	724.8460083	1	0	13675.332	1	0	1	5907.46289	7038.61995	26.2917193	9026.40137	9026.40137

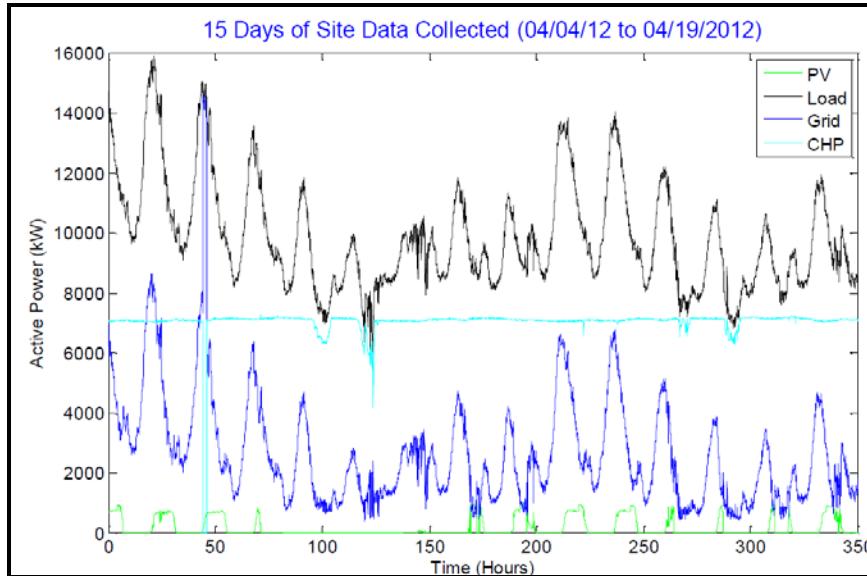


Figure 9: Sample Data Collected from the Base

5.0 PERFORMANCE RESULTS

The following performance objectives presented in this section define the specific means by which this project meets its goals. Data collected during the demonstration will provide the information necessary to assess the effectiveness of the various strategies used. There are three high-level quantitative benefits which the performance objectives provide:

- Increased renewable energy usage and reduced greenhouse gas emissions
- Increased energy efficiency
- Increased energy surety

This demonstration will also directly impact two qualitative objectives:

- Regulatory and End User Acceptance
- User satisfaction

A third qualitative objective, Scalability across the Department of Defense will be a benefit, but no attempt will be made to definitively quantify it. The tools, techniques and strategies demonstrated will be applicable to almost all power delivery systems, regardless of size. The capabilities should be applicable in fixed bases as well as temporary and mobile conditions.

5.1 SUMMARY OF PERFORMANCE OBJECTIVES AND OUTCOMES

Performance objectives in Table 1 are all quantitative, thus can be measured. Each objective has a specific metric, data requirements and success criteria. This table is reproduced from the Executive Summary below.

Table 1: Performance Objectives and Outcomes

Performance Objective	Metric	Data Requirements	Success Criteria	Results
Quantitative Performance Objectives				
Increased renewable energy usage and reduced fossil fuel usage	Ability to optimize more renewables and natural gas based resource	Estimate potential displacement of fossil fuel based generation by using renewables and other natural gas based DGs. Calculate GHG emissions reduced.	Capability to use and optimize up to 100% of emission-free energy resources.	As described by the results in section 5.2, 100% of the renewables were used all the time.

Table 1: Performance Objectives and Outcomes (Contd.)

Performance Objective	Metric	Data Requirements	Success Criteria	Results
Increased energy efficiency	Operate DGs and boilers at their highest power factor and efficiency regions	Power time histories – imported power, generated electrical power by the DGs, generated thermal power; NG and boiler usage	Comparing with using multiple DGs and boilers used to meet the same demand, microgrid controller can show up to 2-3% efficiency over the year improvements in a microgrid with a few boilers and one CHP. This number is expected to increase to 10-15% with more CHPs and energy storage.	As discussed in the results of section 5.2, adjusting the heat vs. electrical outputs of the CHP 2-4% efficiency is possible in a conservative estimate. In certain situations and definitely with more assets much bigger increase is possible.
Increased energy surety	% of extra critical loads that can be served in absence of grid power	% of non-critical load reduction (e.g. 2 degree increase in thermostat settings) in building loads	Based on the availability of non-critical loads during the hours of islanding, the target is to serve 10% of extra critical loads and hence provide nearly 100% longer service to this 10% load assuming that Cogen capability remaining same all through the islanded operation.	As discussed in the results of section 5.2, a sizable amount of electric load can be dropped instantly by managing the building loads. Depending on the number of buildings participating, 10% of reduction of aggregated loads is possible in few seconds to 10-15 minutes timescale without tripping the whole building or sacrificing too much comfort.
Qualitative Performance Objectives				
Regulatory and End User Acceptance	Degree of Acceptance	During training and demonstration show how microgrid can be a “win-win” proposition between regulators and end-users	Favorable response from the microgrid operators as well as their interactions with the utility/regulators.	As described in section 5.2, favorable response is obtained from the microgrid operators. Also the project received good feedback during presentations at the conferences with utility representatives.

Table 1: Performance Objectives and Outcomes (Contd.)

Performance Objective	Metric	Data Requirements	Success Criteria	Results
User satisfaction	Degree of favorability	Informal Interviews	Favorable opinions and constructive comments expressed by stakeholders.	Informal discussions with the Base personnel were very favorable. The key testimony was their desire to expand the technology for rest of the Base.

5.2 PERFORMANCE RESULTS DISCUSSION

Increased Energy Efficiency:

This measure quantifies the effectiveness of the MCS to manage electrical and thermal energy within the microgrid. This is expected to provide higher benefits than managing the electrical energy all by itself, especially when one primary distributed energy resource is a Combined Heat and Power unit which can generate both electricity and heat. To determine the efficiency improvement, the data requirements include: the natural gas (NG) consumption by the Co-Gen as well as the boilers of the high temperature, hot water (HTHW) system, the active and reactive power produced by the Co-Gen, the input/output temperatures and flow rates within the HTHW system. Comparing with using multiple DGs and boilers used to meet the same demand, it is expected that the microgrid controller can show up to 2-3% efficiency improvements over the year in a microgrid like Twentynine Palms with a few boilers and one CHP. This number is expected to increase to 10-15% with more CHPs and energy storage. This will be extrapolated (as described in section 6) to obtain an estimate of overall increase in energy efficiency possible across a DoD Base, by the technology developed in this program.

As described in section 3, this measure quantifies the effectiveness of the MCS to manage electrical and thermal energy within the microgrid. To do so the following steps are taken:

- 1) Obtained data of the natural gas consumption by the Co-Gen as well as the boilers
- 2) Obtained electrical energy imported from the grid
- 3) Computed total energy consumed and the energy cost
- 4) Compared 3) with total energy consumed using multiple DGs and boilers used to meet the same electrical and thermal demand.
- 5) Made an optimization of the split of thermal to electrical generation needed to meet the thermal and electrical loads. Also as per the current practice the CHP was commanded as close to its rated value as possible (depending on the demand at a given period of time).

Figure 10 shows the results of the optimization explained above. First the optimization was started at the nominal heat and electricity outputs from the CHP. The optimal cost output for this case is considered 100%. Initially, to meet the thermal demands, the heat output was given a higher preference till all the thermal demands are met. However the electrical command goes more and more away from its nominal output and the optimal cost increased, which implied that

the this trajectory (red lines) is not optimal. From this point, the heat output was kept constant but the electrical output was given a higher preference. By doing this, the CHP electrical command started rising and came back more towards its nominal rating and the optimal cost started coming down (green lines). Finally the lowest feasible optimization output was found which maximized CHP electrical command with lowest optimal cost. This gave the right heat-electricity ratio for the thermal load and the optimal cost was typically 2-4% (2.1% in Figure 8) below the 100% cost output obtained with the nominal heat-electricity ratio for the CHP. Once this split of thermal vs. electrical outputs was decided by the process described in this paragraph, it can be kept constant throughout the season till the thermal load changes considerably.

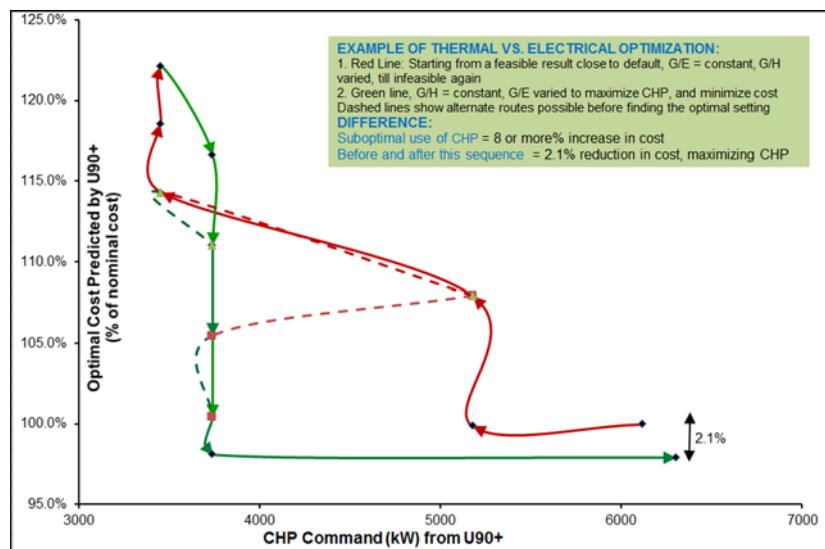


Figure 10: Results of optimizing thermal and electrical outputs of a Combined Heat & Power unit

Thus we can conclude that microgrid controller can optimize up to 2-3% efficiency improvements over the year in a microgrid like Twentynine Palms with a few boilers and one CHP. This number is expected to increase to 10-15% with more CHPs and energy storage and will be validated in Phase 2.

Increased Energy Surety:

The project has demonstrated capability to control loads from the centralized microgrid controls. Building 1130 was chosen to demonstrate that non-critical loads in the building can be either completely turned off (e.g. unnecessary lighting) or turned down (e.g. by increasing the thermostat settings on a hot summer day without sacrificing comfort). Load shedding in this project shall consist of building compressor settings and opening and closing breakers at individual buildings. Since Twentynine Palms MCGACC is an operational military facility, access was not given to all the loads. Though this test was conducted in one major building (PWD building), this can be replicated for any other building loads. By controlling the non-critical loads, it is expected that critical loads can be serviced longer during an islanding event. To do the test, the following steps are taken:

- 1) Chosen appropriate building loads (in this case thermal load)
- 2) Identified the range of temperature that can be changed so that it doesn't sacrifice comfort levels

- 3) Established connection with the microgrid controller via the JCI Metasys system
- 4) The thermostat settings were increased by 2 degrees on a hot summer day in July.
- 5) Checked with the occupants, no noticeable change in comfort levels were reported
- 6) Obtained a plot of load before and after the controls, computed the difference. Any rebound effects of the load either during the tests or after restoration of the thermostat settings were observed.
- 7) Since this test also impacts energy efficiency, an extrapolation of this capability with realistic assumptions of how much of this can be replicated for any other building loads were made and rolled them up to a DoD-wide energy efficiency projection. This will be reported as part of BLCC study in section 6.

The goal of this test is to demonstrate capability of reducing loads at the building level. During the islanding events or other major disturbances, the Base has capability to drop one feeder at a time (based on predetermined priority) or half of one particular feeder using recently installed motorized breakers. This test shows that the Microgrid Control System developed in this project can reduce loads quickly at building levels, if deployed widely. As shown in Figure 11, a sizable amount of electric load can be dropped instantly by managing the building loads without sacrificing too much comfort. In this building 33% of the load reduction is possible in the current scenario. In some cases the drop can be lower and in some cases the whole building can be dropped (if it not essential to provide service) but on an aggregated feeder level 10% of reduction of aggregated loads is possible (assuming one-third of the buildings participate in these tests) in few seconds to 10-15 minutes timescale without tripping the whole building or sacrificing too much comfort.

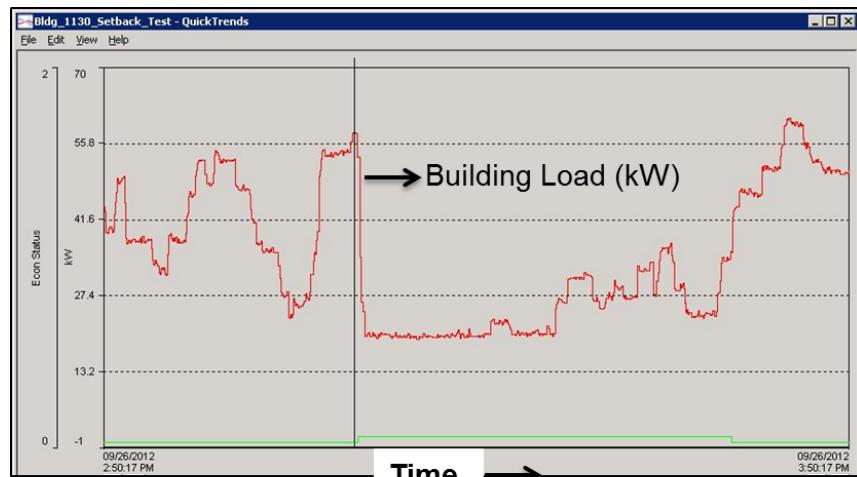


Figure 11: Dropping building loads from MCS for one hour

It could also be noted that after some time the load will rebound as the thermostatic loads like air-conditioners come back stronger to cater to the rise in temperature in this period. So one has to be careful to calculate the benefits on energy savings based on tests like this and it needs much more data to do so. The purpose of the test is not to show energy savings benefits but possible amount of load reduction possible in quick time at the building level in order to give some momentary relief to the distribution generators and keep the microgrid operational as much as possible before considering tripping large amount of load like the whole or part of the feeder. In

the future a hierarchical load management scheme can be developed controlling building loads to feeder loads in a sequence of time, using this concept.

To make sure, that the Cogen is commanded to pick up 100% of the critical loads, islanding data from January and February 2012 were played back in real time at GE Laboratory and the results are shown in Figure 12. As seen in the figure, the CHP command (in red) quickly catches up with the actual load (in magenta) after grid power (in orange) goes down.

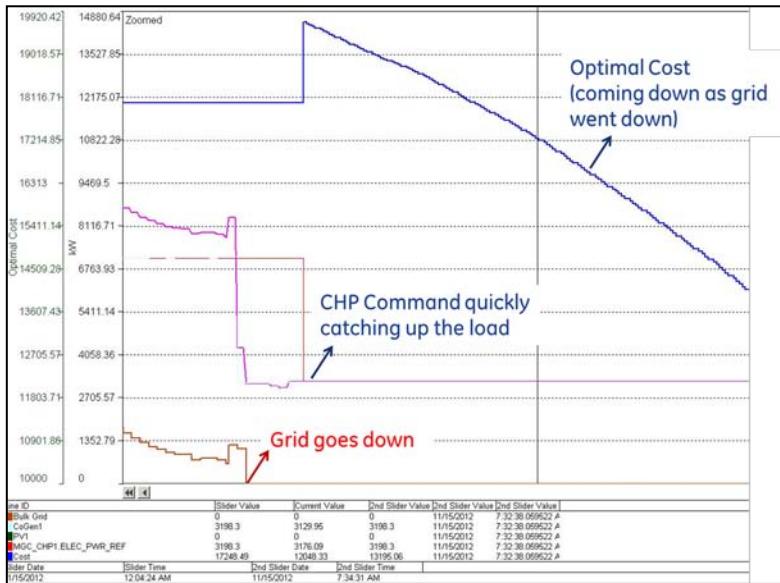


Figure 12: Testing U90+ response to an islanding event

Increased renewable energy usage and reduced fossil fuel usage:

Operability of renewables is given the highest priority in the microgrid objective function. Before optimizing other distributed resources, PV (in case of Twentynine Palms) gets the highest priority in the Unit Commitment. This will be true even during Islanded mode operations. While it is hard to quantify the “maximum utilization” or renewables since it depends on available sunlight, the project will estimate potential displacement of fossil fuel based generation by using renewables and other natural gas based DGs and calculate GHG emissions reduced. Currently about 50% of total energy in AA substation comes from the Southern California Edison (SCE) grid and the Base generates about 0.7-1% of GHG emitted by all of SCE territories. So one way to obtain an estimate of overall reduction in GHG possible across a DoD Base is to extrapolate the average utility fossil fuel amount that can be displaced by the technology developed in this program. However it is found that BLCC tool prescribed to calculate the life cycle cost, also estimates the GHG emissions and this tool is actually used (as described in Section 6) to give an estimate of reduction of emissions by 100% utilization of available renewable energy.

To evaluate this feature, several experiments were conducted in the GE laboratory and the difference in cost with and without renewables during a whole day was noted to determine the effect of the renewable energy contribution on optimal cost. Care was taken that for the case without renewables, they were disabled before sunrise and re-enable only after the sunset in that day. As seen in the Table 3, the optimal cost increases up to 5.4%. Later offline calculations showed this was roughly the amount of energy that renewables would have provided in that day

if they were not disabled. This shows that the microgrid controller optimization takes into account 100% of the renewables available in a given day.

Table 4: Test Results Showing Effect of Renewable Integration

Test Condition	Optimal Cost (%)
System running with renewables (PV) enabled	100.0%
Output from next dispatch cycle after renewables are disabled at 6:45am (sun just coming up)	104.7%
Output at 10:30pm after the full PV cycle. Peak PV during the day was 865kW	105.4%
Output from next dispatch cycle after renewables are re-enabled at 10:30pm	100.1%

User Satisfaction:

Reduced Operator involvement during operations is a metric that measures the effectiveness of the MCS to manage the complex interaction of electrical and thermal energy within the microgrid. Although the MCS will include an Operator event log, which will enable the capture of the interaction of the Operator with the MCS. Through agreement with the Twentynine Palms DPW Office, the base will have the flexibility of keeping some assets under manual control. User satisfaction is also guaranteed by co-locating the operator interfaces through bigger visual inputs and seamless operation from one screen to another. Figure 13 shows before and after the implementation of integration of all the user interfaces (JCI and GE systems). The four flat-panel monitors installed can be seamlessly operated from one screen to another with a single keyboard and mouse. Informal interviews of the operators were conducted after the installation and obtained very positive feedback.



Figure 13: Before and After Installation of New Operator Interfaces

Regulatory and End User Acceptance:

Regulatory and End User Acceptance are always key challenges for any new technology and microgrid is no exception. During the training and demonstration phase, this project aims to show how microgrid can be a “win-win” proposition between regulators and end-users. The team will organize series of demonstrations and outreach events, participate in conferences and workshops and through their interactions with the utility/regulators and other key stakeholders

for microgrids in the DoD sector, influence regulatory and end-user acceptance. To energy utility stakeholders and regulators, GE and the Base personnel have presented the project in several conferences and workshops across the country. A list of these meetings attended during the course of this project is:

- Twentynine Palms Microgrid Overview; Microgrid Exchange Group, May 2010
- Microgrids for Installations, USAF Personnel Visit to GE, June 2010
- Microgrids, GovEnergy, August 2010
- GE Microgrids, TFT Network Energy, Oct 2010
- “Microgrid Technologies – 29 Palms – Distribution Optimization in Smart Grids” - Symposium on Microgrids, Jeju Island, Korea, May 2011
- Military Smart Grids & Microgrids Conference – May 2012
- DOE Microgrid Workshop – July 2012

GE has also started using news media and blogs to receive feedback and acceptance on this technology – these will be discussed in details in section 8.

GE Global Research will work with the GE business units to identify a few key utility customers and representatives from the regulatory bodies. These entities can then be invited for a technology summit or seminars, routinely organized by GE Global Research as customer outreach events. The results of this project can be shared at those events and along with some GE laboratory/Base demonstrations can lead to better dialogues and influence the regulators/utilities to accept microgrid technologies. GE Global Research has started conducting regular “microgrid lab demos” with utilities worldwide whenever such an event is organized.

6.0 COST ASSESSMENT

6.1 COST DRIVERS

Cost of several microgrid elements in Twentynine Palms will mainly consist of hardware, software and installation costs. The items that were purchased for this project are:

- One Computer Server for the Base
- IEC 61850 Software License for CIMPPLICITY
- Cimplicity Software provided by GE Intelligent Platforms (GE IP) – one for testing and validation in the laboratory and one for demonstration at the Base
- GlobalCare service for GE IP Software
- Gateway software
- U90+ hardware and firmware containing the optimal dispatch software provided by GE Digital Energy – one for testing and validation in the laboratory and one for demonstration at the Base
- Computer Cables
- Standard Power Supply
- One Load Panel and one GE F35 relay for laboratory testing
- One APC rack - 24U for Base and one rack with mounts for the GE laboratory.

Table 5: Cost Model for Microgrid Control System

Cost Element	Data Tracked During the Demonstration	Estimated Costs
Hardware capital costs	Estimates made based on component costs for demonstration	\$150,000
Installation costs	Labor and material required to install. Included are the labor and travel costs for GE personnel to visit the Base	\$20,000
Set up and Commissioning costs	Labor and material required to select correct settings and parameters of the controller, testing and retune them as needed. Included effort at the Base (after installation) and at the GE Laboratory	\$100,000
Consumables	Estimates based on rate of consumable use during the demonstration	None
Facility operational costs	Reduction in energy required vs. baseline data	\$4-7MM over 20 years. Explained in section 6.2
Maintenance	<ul style="list-style-type: none">• Frequency of required maintenance• Labor and material per maintenance action	\$5000 per year for GE personnel to visit Base or attend phone calls for trouble-shooting. \$10,000 once every 5 year for license upgrades.
Estimated Salvage Value	Estimate of the value of equipment at the end of its life cycle	Minimal.
Hardware lifetime	Estimate based on components degradation during demonstration	Since industry grade equipment like GE relays and platforms are used, 20 years life expectancy is estimated.

Table 4: Cost Model for Microgrid Control System (Contd.)

Cost Element	Data Tracked During the Demonstration	Estimated Costs
Operator training	Estimate of training costs	Since the control system and optimization are new technical concepts, initial training costs can be higher. Also depending on reshuffling of operators, there may be some recurring training costs. An average training cost of \$2000 is assumed per year which included upgrade of user manuals, operation manuals etc.

Lot of uncertainty might come up while using the installation, set up and commissioning costs for another microgrid facility. These costs are highly dependent on available infrastructure, existing communication equipment and available personnel to support these activities. The costs estimated in Table 4 was based on the already available infrastructure and excellent support given by the Base engineers and their Energy Service Provider (JCI).

6.2 COST ANALYSIS AND COMPARISON

An estimate of lifecycle cost and payback calculations are done using the NIST BLCC model to explain life cycle costs for the microgrid control system. This section will show the input and output results of the model to determine costs and benefits of this technology.

A glimpse of the BLCC model is shown in Figure 14. It uses the Federal Analysis, Financed Project module for an LCC analysis of Energy Savings in energy or water conservation projects funded by the Federal Government. The criteria used as defaults in this module are applicable to all agencies in the Federal Government.

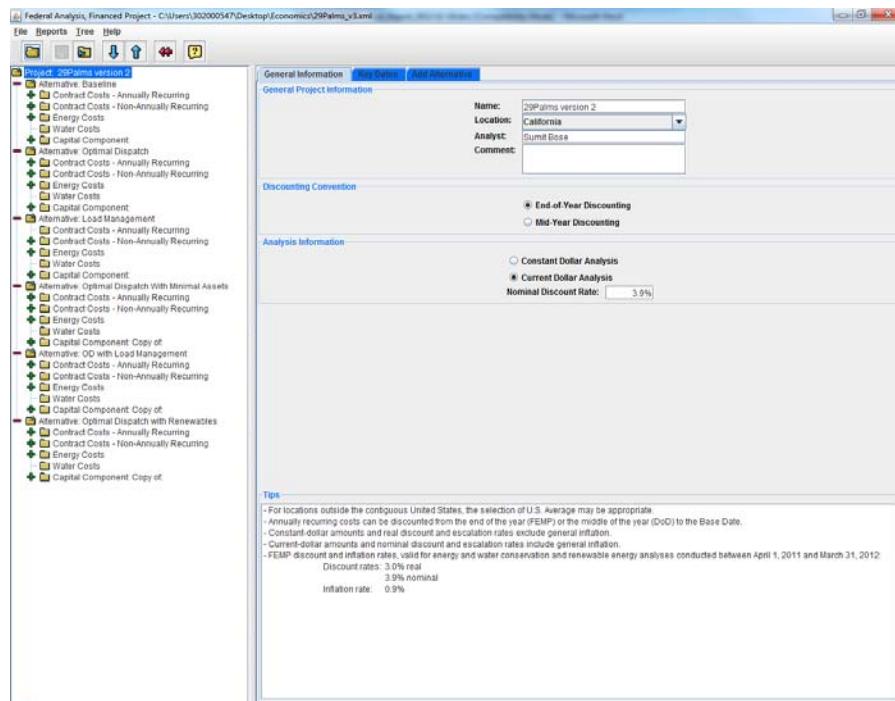


Figure 14: BLCC Model for Twentynine Palms Microgrid

Six alternatives are considered for cost analysis and comparison. They are:

- 1) Baseline: this is based on available yearly energy consumption data from the Base
- 2) Optimal Dispatch Technology with minimal assets – this assumes about 2-3% energy efficiency benefits as described in section 5.2.
- 3) Optimal Dispatch with all assets – this assumes all the planned assets in the Base are deployed (additional CHPs, fuel cell, energy storage etc.)
- 4) Load Management – benefits of energy efficiency on load management is considered. In this case 50% of all the buildings are assumed to raise their thermostat settings by 2 degrees on 75 hot summer days in a year for one hour each day.
- 5) Optimal Dispatch and Load Management combined
- 6) Optimal Dispatch with Renewables: as described in section 5.2, this alternative is considered only to determine the benefits obtained by GHG emission reduction.

The BLCC outputs are shown in Appendix C. Based on these outputs and following NIST guidelines, SIR (Savings to Investment Ratios) and AIRR (Annualized Internal Rate of Return) are calculated for some of these alternatives and GHG benefits for renewables. Table 2 summarizes these results and is reproduced from the Executive Summary.

Table 2: Cost Benefit Summary

Case	SIR	AIRR	Total savings	% energy used	Emission (Tonnes/year)		
					CO2	SO2	NOx
Baseline, 29Palms (estimated)	NA	NA	\$0	100%	71948	479	95
Optimal Dispatch with Minimal Assets	6.59	13%	\$4,218,818	98%	51733	314	51
Optimal Dispatch With All Assets	11.54	16%	\$7,386,162	98% for 3 years, 95% for next 9 years and 90% thereafter	51176	314	51
Load Management Only	2.05	7%	\$3,682,421	99% for 4 years, 98% for next 5 years, 96% for next 5 years and 95% thereafter	51596	314	51
Optimal Dispatch with Load Management	4.19	11%	\$8,465,257	97% for 3 years, 93% for next 6 years, 91% for next 3 years, 85% thereafter	50783	314	50
Optimal Dispatch with Renewables	Not calculated, varies for different types of renewable resources and their costs				50538	314	50
Difference in emission (baseline with renewables)					21410	165	45

There is one interesting point to be mentioned on Table 2. Optimal Dispatch with Load Management (case 5) shows higher energy savings than Optimal Dispatch with All Assets (case 3). The reason is partly explained in section 5.2. Energy savings benefit for load management needs more data and wider deployment of this type of load controls. Assuming around 10% of total loads being reduced for 100 hot summer days for only 40 minutes per day (after which the load bounces back and there may not be any energy savings beyond that timeframe) only 0.4-0.5% of energy can be saved. With more adoption of these technologies and other advanced demand response technologies, number of buildings and the duration can be extended. Hence in the above table (Table 2), around 5% of energy is assumed to be saved after 10 years. Also it is assumed that the buildings may need special controls and building energy management system to interface with the microgrid controller in order to achieve this. This project used the existing building energy management system from JCI but in the above table, some cost is assumed per building – which also rises with more number of buildings. This rise of initial upfront cost is higher than the benefits realized later from energy savings and hence this shows lower AIRR and SIR compared to the optimal dispatch which though saves lower energy than when coupled with load management but the upfront cost is also relatively lesser.

7.0 IMPLEMENTATION ISSUES

The project had a relatively seamless implementation and system integration during the demonstration phase due to excellent camaraderie and support provided by the Base engineers and members of their Energy Service Provider (Johnson Controls Inc.). Without their cooperation and teamwork, this project would not have reached this stage of success.

There are a few lessons learnt that can be discussed, which can aid future implementation of the technology. They are as follows:

1. The Base is not allowed to export excess power generated by its DER to the Southern California Edison beyond a very small threshold. Negotiations are currently going on between the two sides and if this limitation can be lifted so that more value out of the microgrid control system can be derived.
2. Time of use or Real time pricing scheme can enhance energy efficiency benefits at certain points of the day and the optimization can provide appropriate commands depending on the price of electricity. All the current benefits discussed in this report are based on a single average electricity rate.
3. Microgrid control system can take into account and do continuous set-point control of diesel gensets. But this feature was never implemented due to EPA regulations which allow operation of these gensets only 200 hours in a year (other than emergency operations) and hence they are reserved for maintenance related events only.
4. The project was delayed due to fiber optic installations across the Base which will enable microgrid control system aware of all the other substations and their loads, outside the AA sub.
5. Though testing has been conducted to make the U90+ work in automated mode, the final connection of its commands to the actual equipment is not made. This is being planned after the Base engineers are convinced of the operation of the controller and the fallback features.
6. Though the Base has a good size solar plant, it does not have the state-of-the-art interfaces. So external commands to control its active and reactive power outputs is not possible. Also there is large amount of distributed PV across the Base, but they are not aggregated or accounted by any existing data acquisition system.
7. The Microgrid Control System works in a secure and dedicated network without access to external internet. Hence any external weather forecast information is unavailable to predict thermal or electricity demands during the day. Hence U90+ has incorporated its own forecasting routine using historical information. While this is expected as a standard practice for all DOD bases, this could be specified as a requirement in the initial design phase of the project.
8. The Base had a fuel cell which was not operational during the course of this project. This would have added extra capability in the optimizer. However integration of a replacement fuel cell is planned in the next phase of the project.
9. The Base uses a few third-party vendors as contractors for communication setup or testing islanding mode etc. Continuous coordination is necessary to work with the schedules of GE engineers, the Base engineers, JCI and the third party contractors as needed. Most of the time, this did not impact much on the project schedule.

8.0 TECHNOLOGY TRANSFER

8.1 COMMERCIALIZATION AND IMPLEMENTATION

GE has two businesses under this program and both of them are very interested to take the technologies developed by GE Global Research to market. First, GE Intelligent Platforms provides world class commercial control software in their Proficy suite. Proficy quickly integrates information from across a facility to gather, correlate and interpret critical business intelligence efficiently. It also helps trace process and product data, providing an accountable and up-to-date status of operations at any time. Second, GE Digital Energy provides products including distribution automation controllers which allow utilities to monitor and control assets, maximizing the flow of electricity and increasing service reliability.

GE Global Research has already engaged both businesses, through the prior relationship with DOD ESTCP, and will continue to work with those businesses if awarded this proposed program. The method by which the technology will be transitioned to the DoD end user(s) involves the actual usage of the MCS on the base's identified microgrid via GE Digital Energy (microgrid controller and Volt/VAr control) and GE Intelligent Platforms (supervisory controller, the HMI, the BEM, and certified network communications) hardware and software tailored for Twentynine Palms operation.

GE is a global technology and manufacturing leader in a broad variety of products, including green energy and smart grid to reduce dependence on fossil fuels while developing the most efficient, reliable, and economical solutions for GE customers. GE is uniquely capable of creating technology and delivering products for energy generation, including solar, wind, and gas turbines, energy storage, power conversion, grid integration, and software for managing all of this integration. For the proposed project, GE Global Research will lead the technology development and demonstration and work with GE Digital Energy and GE Intelligent Platforms, both of whom are active contributors to the existing and proposed programs. These GE businesses will take the technology to product level maturity, and ultimately commercial products. GE Intelligent Platforms provides world-class commercial control software in their Proficy suite. Proficy quickly integrates information from across a facility to gather, correlate, and interpret critical business intelligence efficiently. It also helps trace process and product data, providing an accountable and up-to-date status of operations at any time. GE Digital Energy provides products including distribution automation controllers which allow utilities to monitor and control assets, maximizing the flow of electricity and increasing service reliability.

The method by which the technology will be transitioned to the DoD and other end user(s) involves the actual usage of the MCS on the Base's identified microgrid. This will be done via GE Digital Energy (microgrid controller) and GE Intelligent Platforms (supervisory controller, the HMI, the BEM etc.) hardware and software tailored for the Twentynine Palms operation. Key commercialization and technology transfer strategies can be:

- 1) There are DoD forcing functions to further utilize the GE microgrid technology across DoD bases, for example, Army, Airforce, and Navy mandates to install 3 GW of renewable energy on DoD bases by 2025. The technology developed in this project is scalable across all these DoD installations.
- 2) DoD is developing an integrated, enterprise-wide data management approach for all of its facilities that incorporates electric metering. According to the DoD Annual Energy Management Report for FY2010[3], cumulative percentage of buildings across DoD installations with electric metering is 95%. The GE technology is not only structured to use GE hardware and software for the microgrid, but is also capable to utilize inputs such as building energy management systems from vendors such as Johnson Control, Inc.
- 3) GE will specify the technology transfer method for the appropriate audience, spanning from regular campus microgrids to military bases to remote communities.

8.2 TRAINING REQUIREMENTS AND RESOURCES

GE Engineers are constantly engaged with the Base engineers and operators to make sure that the technology is well understood and utilized by them. A few undergoing efforts worth mentioning on this topic:

- GE has prepared a detailed instructional manual for the U90+ controller. This will provide great insight to anyone who likes to learn and operate the system. Figure 15 shows the cover page of the manual. A shorter and simpler operation manual is also being prepared.

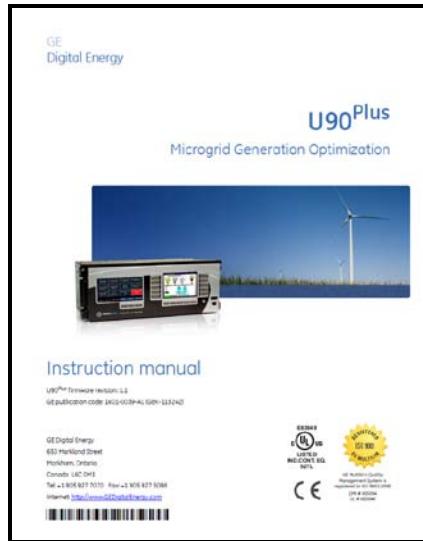


Figure 15: Detailed instructional manual for the U90+ controller

- GE Global Research has a blog site where information of the projects is posted. Also GE Digital Energy has recently started the media to provide short information about commercializing the microgrid controller. Figure 16 shows a screenshot of the blog and

Figure 17 shows a screenshot of the GE Digital Energy News and Events website describing GE's future offering on this technology.

The screenshot shows a blog post titled "Edison's Desk" from GE Global Research. The post features a blue header with the GE logo and the title. Below the header, there's a sidebar with categories like INDUSTRIES, TECHNOLOGIES, LOCATIONS, and THE LATEST. The main content area has a heading "Update on the Twentynine Palms Marine Base microgrid" and a photo of a man, Sumit Bose, speaking. The text discusses the project's status and its potential impact.

Figure 16: GE Global Research Blog

The screenshot shows a news article from the GE Digital Energy website. The title is "GE Introduces an Optimization Solution for Microgrids". The article discusses how GE's Microgrid Control System (MCS) can help manage renewable energy resources and fossil fuel-based resources to optimize microgrid operations and reduce energy costs. It includes a small image of a computer monitor displaying a control interface.

Figure 17: GE Digital Energy News Article

- GE and the Base personnel have presented the project in several conferences and workshops across the country. A list of these meetings attended during the course of this project is:
 - Twentynine Palms Microgrid Overview; Microgrid Exchange Group, May 2010
 - Microgrids for Installations, USAF Personnel Visit to GE, June 2010
 - Microgrids, GovEnergy, August 2010
 - GE Microgrids, TFT Network Energy, Oct 2010
 - “Microgrid Technologies – 29 Palms – Distribution Optimization in Smart Grids” - Symposium on Microgrids, Jeju Island, Korea, May 2011
 - Military Smart Grids & Microgrids Conference – May 2012
 - DOE Microgrid Workshop – July 2012
- GE and the Base will continue to work with DOD to provide information to other DOD agencies, websites etc. about this project.
- A position paper on microgrid energy management for military bases is planned for publication in IEEE and/or other peer reviewed journals.

8.3 DESIGN COMMUNITY IMPACTS

Since the technology is in its very early commercial phase, no changes to design guidance documents, policy/management documents, or design tools are planned at the present time. GE will continue to work with its potential commercial as well as governmental customers to develop or modify these documents as the technology matures.

APPENDICES

APPENDIX A: PERFORMANCE ASSESSMENT METHODOLOGIES

Performance assessment for this project was done with the following systematic and disciplined steps:

- 1) The Base engineers have provided extensive historical data of their power system starting from 2007. These are 5-minute and 15-minute interval data for every month in a year showing the grid import, CHP and PV outputs as well as the electrical demands in the four feeders of the AA substation. Also temperatures at certain key places of the thermal loop was provided from which the thermal demands were estimated.
- 2) GE had first deployed the Microgrid Control System in their laboratory of GE Global Research in July 2011. Later the same exact hardware and software were deployed at the Base in April 2012 (Figure 18). The team monitored initial performance data at the Base and then trained the Base personnel to provide them periodically the performance data via a secure file transfer mechanism. Figure 18 shows a picture of the system deployed at the laboratory and the system deployed at the Base.



Figure 18: System deployed at the laboratory and at the Base

- 3) Though the GE team has visited several times from April 2012 till date to monitor performance, it is deemed appropriate to test the performance of the controller in the laboratory using both historical as well as current data. Also each test typically runs for a period of 24 hours and some even for days, it is more productive and economical to play back the data from Base in the laboratory as if live data is viewed.
- 4) CIMPLICITY has a feature called Digital Graphical Replay (DGR) let the users go back in time and graphically analyze events that occurred in the past. Using data that is logged in Proficy Historian or SQL Server, the DGR enables to replay graphical screens to determine cause of events or alarms – allowing the user to optimize the settings or prevent conditions that led to alarms. The user can play back from a point in time (Figure 19) or have the DGR search for conditions in the data, and automatically set start and

stop times based on those settings. One can play back in slow motion, real time or up to 10 times the speed. One can also view multiple screens just as if live data is viewed.

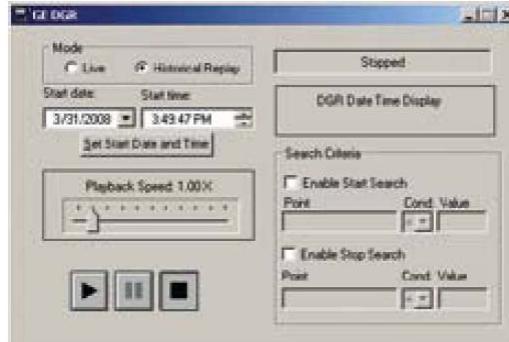
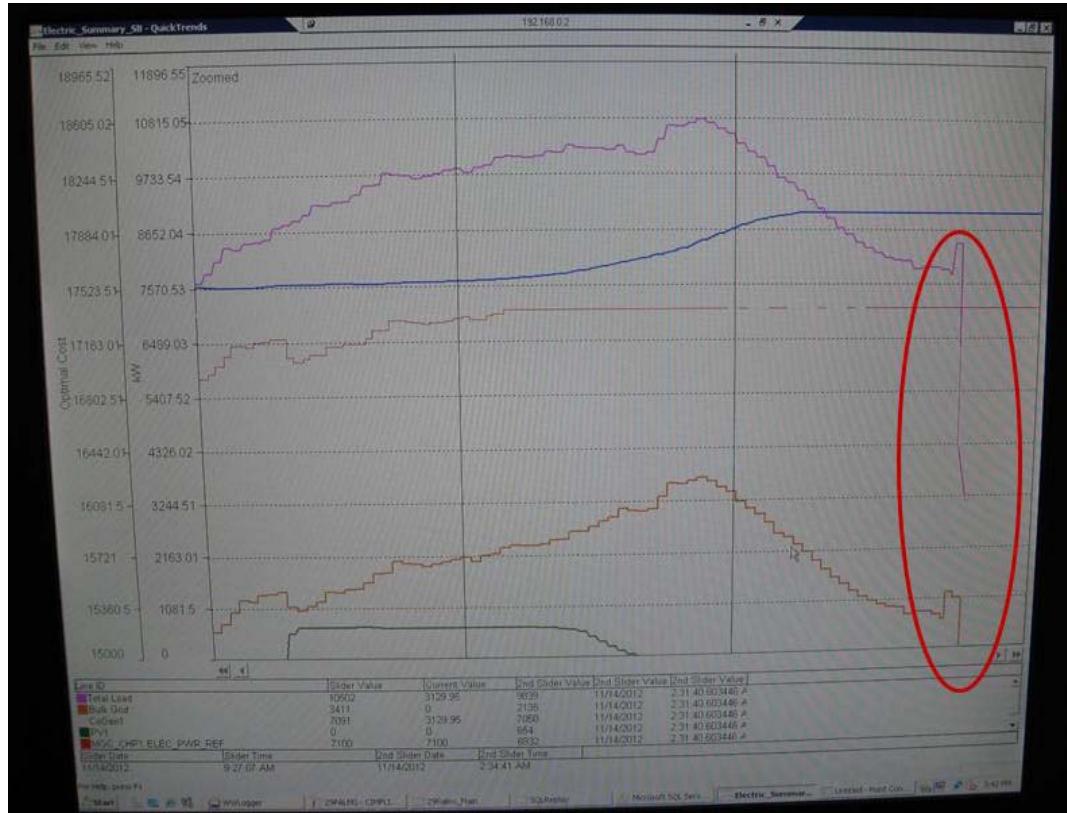


Figure 19: Digital Graphical Replay in Cimplicity

In this project a feature in Cimplicity that is very similar to the Digital Graphical Replay is used to playback the data collected from the Base.

- 5) The performance assessment team used this DGR feature to pass days and months of data to U90+ and its optimization outputs are recorded. Some of the useful displays from the U90+ are shown in Figures 19-21.
- 6) As an example the following figures show how an islanding event on February 15, 2012 at 8:45PM was played back and the performance assessment was conducted:
 - a. Grid falls to zero, loads dropped by Base (highlighted in red in Figure 20)



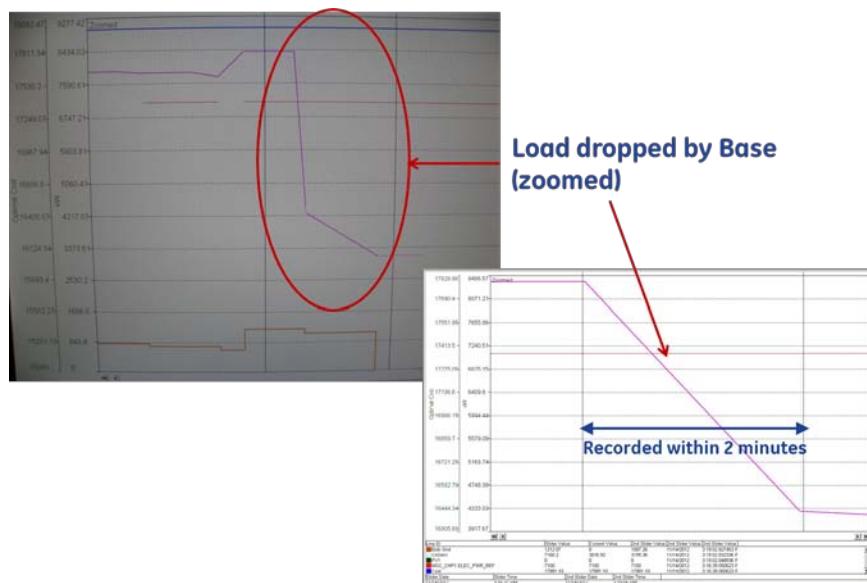


Figure 20: Dropping of Load after Grid Outage

- b. U90+ records the event within the next dispatch cycle (Figure 21).

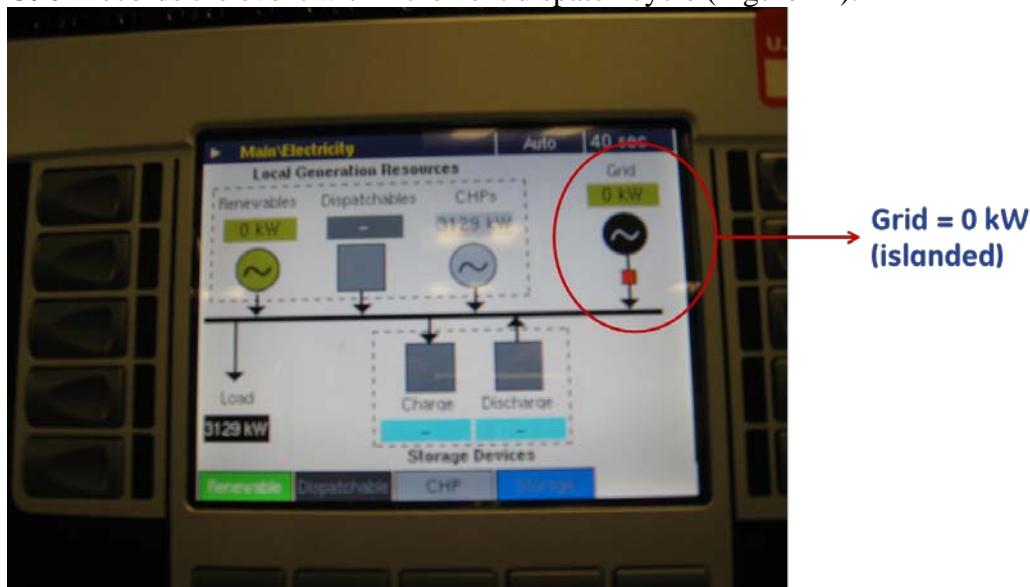


Figure 21: U90+ responding to grid outage

- c. U90+ continues to optimize (Figure 22).

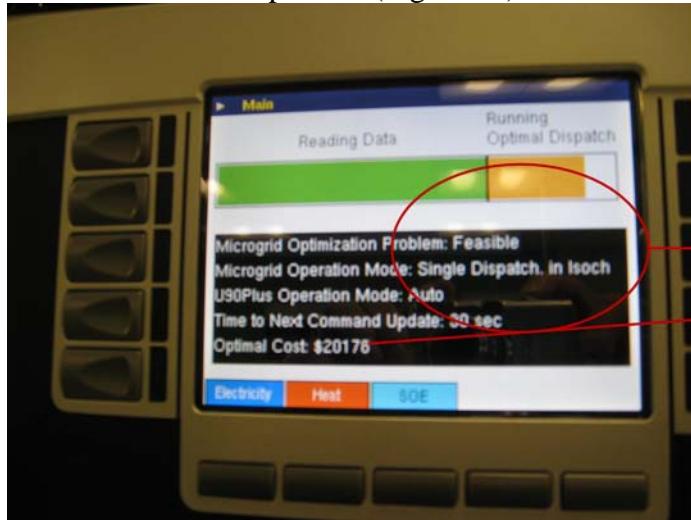


Figure 22: U90+ continues Optimal Dispatch during islanding

- d. U90+ command to CHP was recorded (Figure 23)

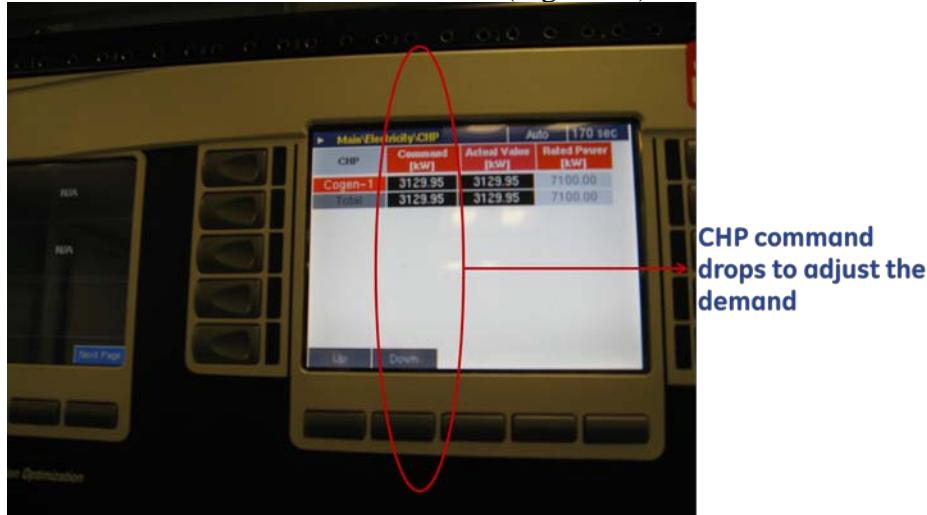


Figure 23: U90+ commands CHP during islanding

- e. U90+ was allowed to run throughout the islanding event and optimize. Once the islanding event was over, U90+ backs down the CHP command to accommodate grid import (Figure 24).

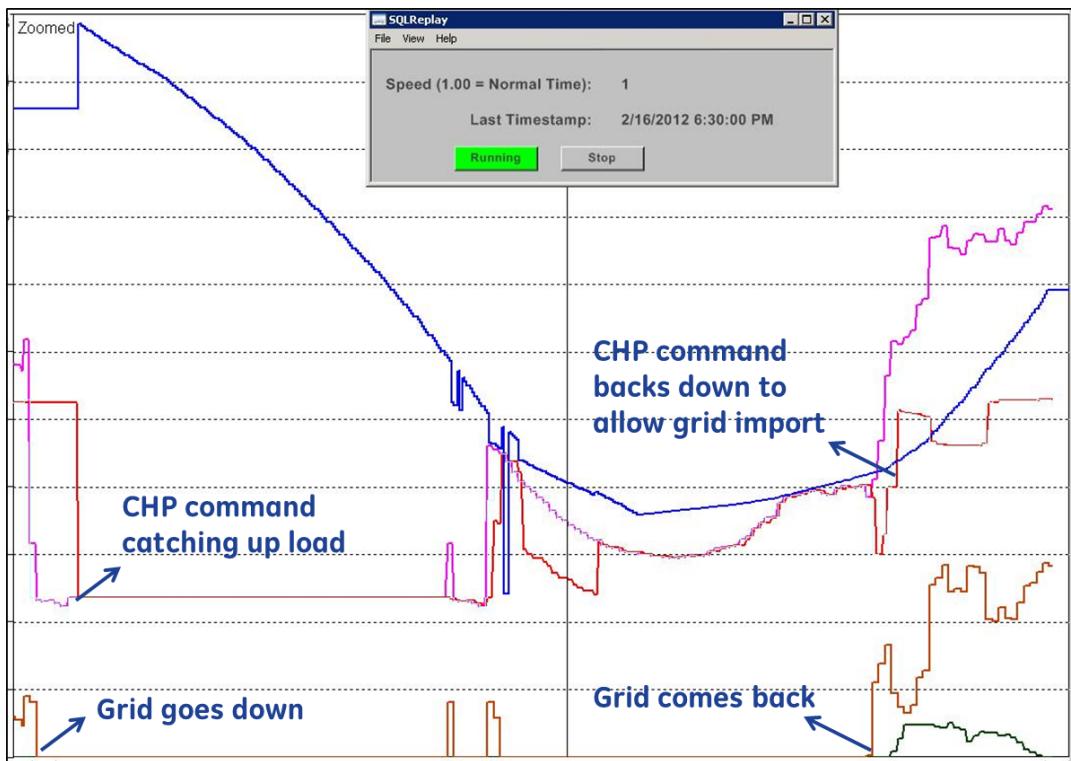


Figure 24: U90+ response during and after grid outage

7) Similar process was adopted to test all the performance objectives as shown in Table 5.

Table 6: Assessment Method for Each Performance Objective

Performance Objective	Assessment Method
Increased renewable energy usage and reduced fossil fuel usage	<ol style="list-style-type: none"> 1) Run a normal day with renewables 2) Replay the same day by disabling renewables in the settings via Cimplicity 3) Record difference in optimal cost outputs, tabulate the results as shown in Table 4. 4) Repeat the same tests for some other days in the year.
Increased energy efficiency	<ol style="list-style-type: none"> 1) Start with a nominal setting of the Electricity/Heat ratio 2) Change the settings via Cimplicity after a few optimization cycles 3) Record and plot optimal cost and CHP commands from U90+ as shown in Figure 10. 4) Repeat the same tests for some other days in the year.
Increased energy surety	Figure 11 was recorded in a separate test at the Base using a Cimplicity interface. Islanding performance was recorded in the laboratory using steps explained in Figures 20-24 of this Appendix.

APPENDIX B: BUILDING LIFE CYCLE COST MODEL RESULTS

A glimpse of the BLCC model is shown in Figure 12. This appendix shows screenshots of the inputs and outputs of the model for the different alternatives studied.

- 1) Inputs for Baseline: this is based on available yearly energy consumption data from the Base
- 2) Inputs for Optimal Dispatch Technology with minimal assets (Figure 25) – this assumes about 2-3% energy efficiency benefits as described in section 5.2.

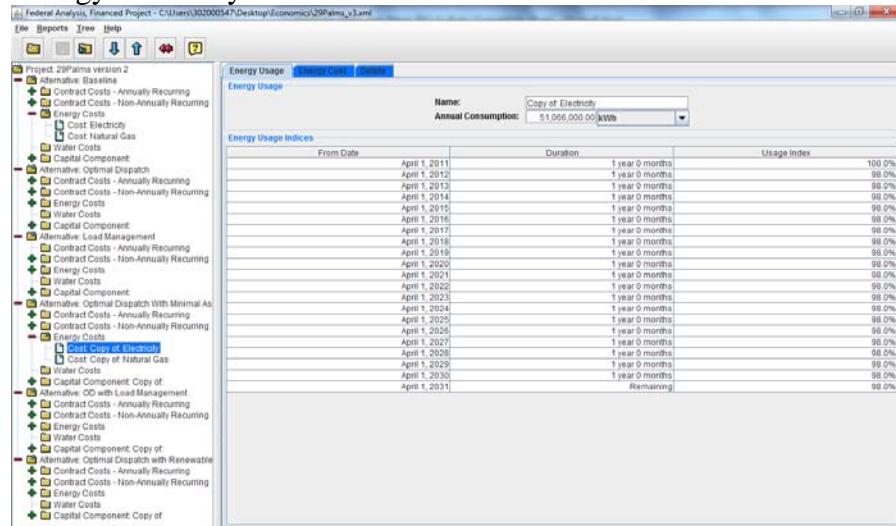


Figure 25: BLCC Inputs for Optimal Dispatch with Minimal Assets

- 3) Inputs for Optimal Dispatch with all assets (Figure 26) – this assumes all the planned assets in the Base are deployed (additional CHPs, fuel cell, energy storage etc.)

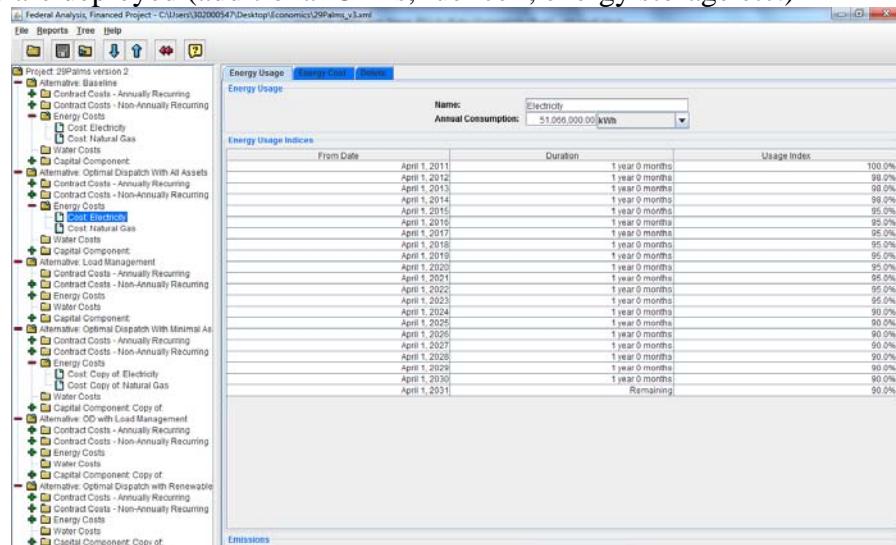


Figure 26: BLCC Inputs for Optimal Dispatch with All the Assets

- 4) Inputs for Load Management (Figure 27) – in this scenario, benefits of energy efficiency on load management are considered. Energy savings benefit for load management needs more data and wider deployment of this type of load controls. Assuming around 10% of total loads being reduced for 100 hot summer days for only 40 minutes per day (after which the load bounces back and there may not be any energy savings beyond that timeframe) only 0.4-0.5% of energy can be saved. With more adoption of these technologies and other advanced demand response technologies, number of buildings and the duration can be extended.

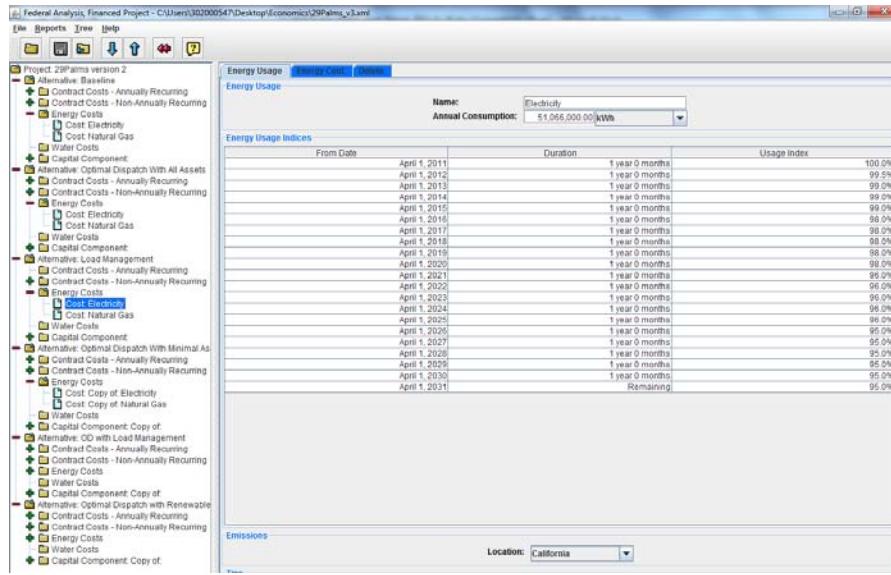


Figure 27: BLCC Inputs for Load Management

- 5) Inputs for Optimal Dispatch and Load Management combined (Figure 28).

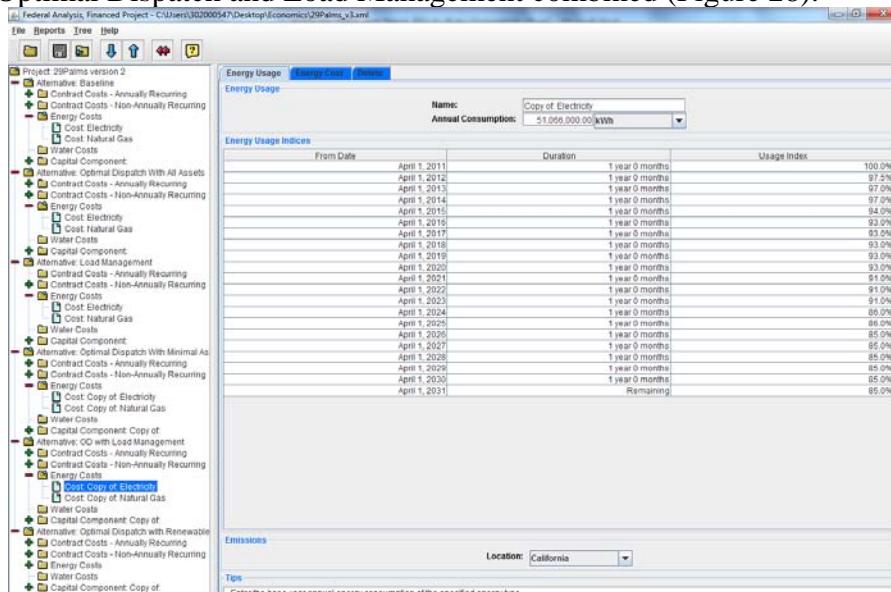
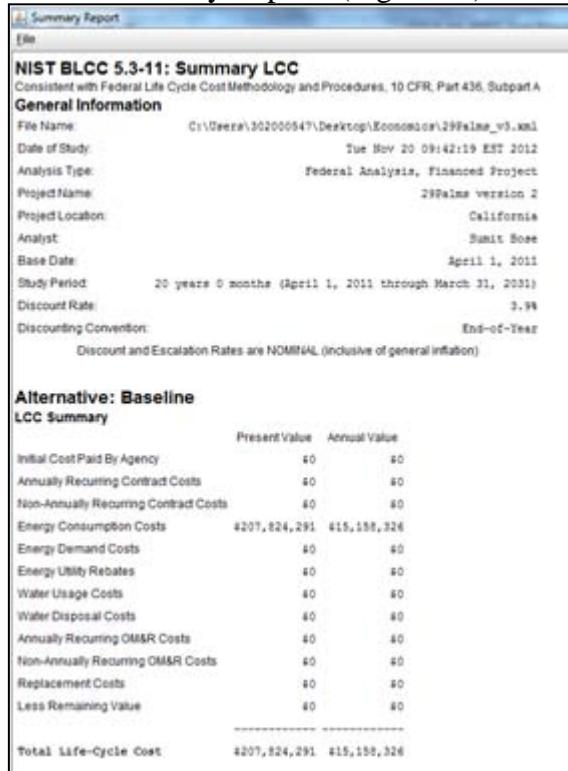


Figure 28: BLCC Inputs for Optimal Dispatch with Load Management

- 6) Optimal Dispatch with Renewables: as described in section 5.2, this alternative is considered only to determine the benefits obtained by GHG emission reduction.

7) BLCC Summary Reports (Figure 29):



Alternative: Optimal Dispatch With All Assets		
LCC Summary		
	Present Value	Annual Value
Initial Cost Paid By Agency	\$0	\$0
Annually Recurring Contract Costs	\$0	\$0
Non-Annually Recurring Contract Costs	\$463,144	\$33,781
Energy Consumption Costs	\$199,904,971	\$14,580,705
Energy Demand Costs	\$0	\$0
Energy Utility Rebates	\$0	\$0
Water Usage Costs	\$0	\$0
Water Disposal Costs	\$0	\$0
Annually Recurring OM&R Costs	\$35,219	\$2,576
Non-Annually Recurring OM&R Costs	\$34,895	\$2,531
Replacement Costs	\$0	\$0
Less Remaining Value	\$0	\$0
Total Life-Cycle Cost	\$200,438,129	\$14,619,593

Alternative: Load Management		
LCC Summary		
	Present Value	Annual Value
Initial Cost Paid By Agency	\$0	\$0
Annually Recurring Contract Costs	\$0	\$0
Non-Annually Recurring Contract Costs	\$1,736,212	\$126,636
Energy Consumption Costs	\$202,393,382	\$14,762,206
Energy Demand Costs	\$0	\$0
Energy Utility Rebates	\$0	\$0
Water Usage Costs	\$0	\$0
Water Disposal Costs	\$0	\$0
Annually Recurring OM&R Costs	\$7,450	\$544
Non-Annually Recurring OM&R Costs	\$4,819	\$351
Replacement Costs	\$0	\$0
Less Remaining Value	\$0	\$0
Total Life-Cycle Cost	\$204,141,870	\$14,889,737

Alternative: OD with Load Management		
LCC Summary		
	Present Value	Annual Value
Initial Cost Paid By Agency	\$0	\$0
Annually Recurring Contract Costs	\$0	\$0
Non-Annually Recurring Contract Costs	\$1,431,194	\$118,976
Energy Consumption Costs	\$197,444,387	\$14,415,821
Energy Demand Costs	\$0	\$0
Energy Utility Rebates	\$0	\$0
Water Usage Costs	\$0	\$0
Water Disposal Costs	\$0	\$0
Annually Recurring OM&R Costs	\$48,474	\$3,536
Non-Annually Recurring OM&R Costs	\$34,999	\$2,553
Replacement Costs	\$0	\$0
Less Remaining Value	\$0	\$0
Total Life-Cycle Cost	\$199,359,034	\$14,540,886

Figure 29: BLCC Summary Reports

8) Emissions Summary from Detailed LCC Report (Figure 30).

Detailed LCC Report			Emissions Summary		
			Energy Name	Annual	Life-Cycle
Total Life-Cycle Cost	\$207,824,291	\$15,158,326	Copy of: Electricity:		
Emissions Summary			CO2	11,977,000.25 kg	239,507,213.79 kg
Energy Name	Annual	Life-Cycle	SO2	2,952.10 kg	59,033.93 kg
Electricity:			NOx	4,920.17 kg	98,389.88 kg
CO2	33,386,720.99 kg	667,643,011.92 kg	Copy of: Natural Gas:		
SO2	168,234.43 kg	3,364,228.08 kg	CO2	38,561,182.85 kg	771,118,082.32 kg
NOx	49,826.81 kg	996,399.79 kg	SO2	311,200.92 kg	6,223,166.31 kg
Natural Gas:			NOx	45,447.66 kg	908,828.74 kg
CO2	38,561,182.85 kg	771,118,082.32 kg	Total:		
SO2	311,200.92 kg	6,223,166.31 kg	CO2	50,538,183.11 kg	1,010,625,296.11 kg
NOx	45,447.66 kg	908,828.74 kg	SO2	314,153.02 kg	6,282,200.24 kg
Total:			NOx	50,367.83 kg	1,007,218.63 kg
CO2	71,947,903.84 kg	1,438,761,094.24 kg			
SO2	479,435.35 kg	9,587,394.39 kg			
NOx	95,274.47 kg	1,905,228.53 kg			

Baseline

With Renewables

Figure 30: BLCC Detailed Emissions Reports

APPENDIX C: MANAGEMENT AND STAFFING

The testing and demonstration are conducted by GE Global Research and GE Multilin engineers working closely with Twentynine Palms Site Engineer and Energy Manager. The ESCO in the site is JCI and a resource from JCI is also identified. The contacts of each of these individuals are provided below (alphabetically after the PI).

1. Summit Bose, GE Global Research, bose@ge.com 518-387-5353
2. Dave Doerge, GE Global Research, dave.doerge@ge.com 518-387-7537
3. Amir Hajimiragha, GE Digital Energy, amir.hajimiragha@ge.com 905-927-5200
4. Larry Krause, GE Intelligent Platforms, larry.krause@ge.com 518-464-4520
5. Michael Miller, GE Digital Energy, Michael.Miller3@ge.com 905-927-5036
6. Rick Piel, GE Global Research, pielr@ge.com 518-387-4792
7. Marques Russell, Twentynine Palms, marques.russell@usmc.mil 760-830-8027
8. Bobby Sagoo, GE Digital Energy, bobby.sagoo@ge.com 905-927-5183
9. Gary Morrissett, Twentynine Palms, gary.morrissett@usmc.mil 760-830-5128
10. Brandon Saunders, JCI, Brandon.J.Saunders@jci.com 760-830-8161.

APPENDIX D: REFERENCES

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Additional Appendices – Action Items from IPR and Other Meetings

- 1. Provide more explicit/less general direction towards addressing system redundancy and reliability in the C&P and Final Reports. Plan to include a discussion regarding these issues in the Final and C&P Reports in the Issues for Implementation section as well as in the Cost Analysis sections of your reports, as appropriate. In particular, address the issue of generation capacity needed to meet critical loads during a grid outage and what degree of redundancy in such capacity may be advisable given the mission essential nature of maintaining critical loads.**

The Base has about 5MW of back-up generators in the Mainside area (mainly AA and N subs). These are mostly run by diesel though there are a few natural gas and propane-based as well. The main advantage of these generators is they provide redundancy of backup when the grid goes down and the CHP unit cannot support all the critical loads. In usual situation the CHP can pick up a lot of these loads as well. So the amount of redundancy and the associated cost seems rather high. However the diesel gensets are run very seldom due to EPA regulations which allow operation of these gensets for only 200 hours in a year. Maintenance of these gensets is also an issue and at the present moment they cannot be operated remotely and needs human labor for testing their turn on/off capabilities. To make a balance of redundancy and cost-effectiveness the following options can be considered:

- Use some of the non-essential gensets for optimal dispatch even within the 200 hours/day constraints. May be they can be used for (say) 75 hot summer days only during the peak demand.
- Consider remote turning on-off of those gensets which can be connected with the existing communication network. GE will explore this option with the Base in Phase 2 of the project. This is expected to reduce the maintenance cost to a large extent. If this is done, it would be useful to gather statistics on how often the generators are available and functioning. This would help highlight how reliable they are as backup generators in general and, if they are unreliable, would indicate areas for improvement for the base, areas where the microgrid increases energy security, and areas where a large CHP or integrated DG assets can increase energy security over existing methods. This would help demonstrate the true value to energy security.

- 2. In your Final Report, discuss:**

- a. The impact of the microgrid project on metering at Twentynine Palms**

This project has a good impact on metering at Twentynine Palms. Although the Base was well-instrumented even before the project, the HMI system created for this project gave a lot of information of the microgrid in one common place. Also co-locating the user interfaces through bigger visual inputs and seamless operation from one screen to another (figure 11) helped operators navigate the metered data relatively easily and more effectively.

- b. Cyber security insights, lessons learned, and recommendations.**

Three main cyber-security strategies that are considered for the Microgrid Control System are modularity, DIACAP compliance and virtualization. Modularity compartmentalized MCS functions, each with specific interfaces and methods. Thus changes within a module, so long as

it provides the required methods and uses the defined interfaces, is transparent to the rest of the system. Modularity facilitates configurability, upgradability and graceful degradation. In the MCS, each key characteristic is provided by a distinct module. Module design varies. In some cases, the module is created at the application layer; others require modularization at the OS layer. Modules are also part of the sub-system incompatibility solution; where necessary, translation modules can be inserted.

Sub-system incompatibilities in the MCS did not allow three of the required subsystems to co-exist on the same computing device. One of the specialized, new products is not designed to communicate over the loopback interface, so cannot operate in a common environment with the MCS. Two others, communication protocol translators, are not built to operate on Windows Server 2008, so require a separate environment. From cyber-security point of view, it was ensured that all the software and operating system are compliant with the DIACAP process that the Base is going through. One lesson learnt was using Windows Server 2003 for one of the virtual machines which was not DIACAP compliant (and was replaced later in Phase 2). DIACAP was not part of scope for this phase of the project. GE is working with Base on their effort for DIACAP certification in Phase 2 and results of this effort will be included in that report.

Virtualization provides a plethora of benefits including restoration from a corrupted environment. Perhaps the best known is efficiency; rarely do systems optimally utilize physical resources. Virtualization enables resource sharing, thus satisfies the need to minimize resource consumption on-site. In a virtual environment, each virtual machine is a module and the virtual network(s) connecting them enable interface creation. Thus OS layer modularization can be effected using virtualization; a key capability is rapid configuration. In addition, a virtual environment can be stored as a configuration file and snapshots made of virtual machines. Recovery from a failure down to the OS level is as simple as copying snapshot files. Even replacing a corrupt virtual environment is easy; restore from the configuration file.

Finally the forecasting techniques used in the project were designed so that there is no need to connect to the external internet for any kind of weather or demand forecasting. Instead methods using historical system data were chosen for the purpose.

c. The various economic options an installation may pursue to install a microgrid: self-funded and managed, working with an Energy Services Company or a hybrid approach.

At this stage of development, working with an Energy Services Company seems to be a big plus. The project had a relatively seamless implementation and system integration during the demonstration phase due to excellent camaraderie and support provided by the Base engineers and members of their Energy Service Provider (Johnson Controls Inc.). Without their cooperation and teamwork, this project would not have reached this stage of success.

Another strategy that favors use of an Energy Services company is post-installation operation and maintenance. Since energy efficiency is a key value proposition for Energy Services Company, it makes most sense for them to maintain and operate the microgrid optimization

controller to even enhance the energy efficiency aspects beyond the period of performance. This aspect of this project is being discussed and still evolving.

3. *In your Final and Cost & Performance Reports, discuss the creation, availability, and use of data collected by the microgrid control system and how the data may interface with future enterprise energy data management systems.*

The MCS uses the Proficy HMI/SCADA – CIMPPLICITY, which has the ability to log point data to a Microsoft SQL Database. This data can be point values, alarms, or potentially events that have happened in the CIMPPLICITY project. When a CIMPPLICITY project is running it is maintaining a list of point values. These points can be based off of a Device such as a PLC, or calculated internally. These points can be logged to the database to keep a historical record of the data values that were obtained. The CIMPPLICITY Database Logger Option inserts the data into the database. There are two processes that do the inserts to the SQL Server; the Point Datalogger (PTDL) process – which handles point value logging, and the Datalogger Process (DL) – which handles alarm and event logging.

Appendix A explains in more details how the data collected by the MCS is used for monitoring and performance evaluation. All these data are currently available to the Base as well as GE.

4. *Explain how this microgrid system will operate in an islanded mode with the existing inverters that are designed to trip at minimum and maximum frequency thresholds. In your Final and Cost & Performance Reports, discuss the impact of deliberately creating an unstable microgrid system using components of a legacy system, like inverters, that were designed for a stable system.*

The inverters that are currently in the Twentynine Palms microgrid are from the solar plant. These are not the state-of-the-art inverters and they primarily work as current-source devices. External commands to control their active and reactive power outputs are not possible. During islanding operation it helps if the inverters are voltage-source types which can be set for voltage and frequency droops so that they can handle certain deviations of voltage and frequency. If the microgrid is stably islanded and the voltage/frequency maintained by an isochronous device (e.g. the CHP at Twentynine Palms), these inverters can be kept online as long as the system is stable and the voltage and frequency limits are not violated.

However if these legacy inverters are used during an unstable microgrid scenario, the best option is to trip them during such a condition. The only way to keep them handle instability of voltage and frequency transients could be to add additional devices at their terminals. Different solutions are found to support the transient behavior in case of changes in the grid voltage. Mechanically switched capacitors, synchronous condensers and voltage source static VAR compensators such as STATCOMs can be used to regulate voltage as shunt compensator to improve the grid interface. However all these devices will add extra cost to the microgrid. Hence for a system where percentage of such inverter-based resources are low (as currently in Twentynine Palms), these devices may not be cost-effective even with the additional value of energy reliability. As the solar industry matures to adopt more state-of-the-art inverters with capabilities of VAR control, voltage ride-through etc. they can be adapted for microgrid operations.

- 5. In your Final and Cost & Performance Reports, include the following:**
 - a. Discuss the advantages and disadvantages of integrating or not integrating building emergency generators into the microgrid.**

This item is discussed in Action Item 1.

- b. Discuss the potential impact of having connections to a database for automatic updates of cost drivers, such as cost of electricity and gas.**

Since the microgrid control system uses the cost of electricity and natural gas as part of the cost optimization, it seems that having real time interface with a database for automatic updates of these cost drivers can be beneficial. In fact U90+ can accept cost of electricity in an hourly time-series from an external source. The gas price needs to be set up in the Settings file via the HMI. However once the utility decides the rates (fixed or time of use) for electricity and natural gas, it may not be changed that frequently, so the need to connect to an external database should be balanced with any compromise that might make to the cyber-security requirements for the DOD projects. Operators can change these parameters fairly quickly within a few dispatch cycles of U90+. Only for Real Time Pricing schemes, the automatic updates can be really useful and can be considered.

- c. Discuss the potential impact of models to predict heat or electricity load based on weather forecasts.**

Just like the previous section, the U90+ has the capability to accept prediction of heat or electricity loads from external models/sources based on weather forecasts. However the forecast mode is set to “internal” for this project as DOD projects are not allowed to connect external forecast resources. A more accurate forecasting technique certainly has favorable impact on the predictive models for optimization and can potentially impact the optimal cost. A separate project can be proposed to evaluate the outputs from and “internal” vs. “external” forecast settings for a non-DOD project environment.

- d. Summarize negotiations/discussions with the utility provider to see what modifications, if any, were required for interconnect agreements or other agreements to allow islanding mode during grid outages.**

Islanding operation during grid outages does require collaboration with local utilities. For Twentynine Palms, all these collaboration was handled by the Energy Manager and other engineers of the Base and GE was not involved in any such negotiations/discussions.

- e. Discuss the costs and benefits of the microgrid control system at this point in its evolution.**

This is discussed in great details in Sections 5 and 6.